SESSION 2
CURRENT STATE OF PREPARATION

OVERVIEW OF THE NATIONAL EARTHQUAKE HAZARD REDUCTION PROGRAM

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NATIONAL EARTHQUAKE LOSS REDUCTION PROGRAM

Federal Emergency Management Agency

Background

- 1977 - Congress passed the National Earthquake Hazards Reduction Act (NEHRA)
- Established the NEHRP,
- NEHRP designed to reduce the risks to life and property in the US from earthquakes through the establishment and maintenance of an effective earthquake risk reduction program

NEHRP

- Program agencies:
- Federal Emergency Management Agency (FEMA)
- United States Geological Survey (USGS)
- National Science Foundation (NSF)
- National Institute of Standards and Technology (NIST)

NEHRP

- FEMA's Lead Agency Responsibilities
- Planning
- Coordinating
- Reporting

OSTP Study

- Congressional concerns - November, 1993 - Letter to the President
  - » Program lacks strategic plan
  - » Insufficient coordination among agencies
  - » Not enough research application
  - » Too little research on how to mitigate damage
- March, 1994 - OSTP launched study to review NEHRP, focusing on:
  - » Earthquake research and development
  - » Implementation of the resulting knowledge
- Workshop - June 6-8, 1994

OSTP Recommendations

- Need for expanded program (NEP)
- Add to the four NEHRP program agencies all federal agencies involved in EQ hazards reduction activities
- Establish goals

OTA Study (cont'd.)

- Congress should consider:
  - » Oversight authority for FEMA
  - » Using disaster assistance as incentive for mitigation
  - » Increased role in disaster insurance
  - » Increase financial incentives to promote mitigation

National Earthquake Loss Reduction Program (NEP)

- Implementation
- FEMA to provide coordination and leadership
- Full-time Program Director
- SNDR Overview

NEP

- Budget- neutral
- Does not replace NEHRP, but encompasses a wider range of activities than NEHRP
- An administrative construct of the Executive Branch with no legislative authority
- NEHRP authorities are maintained under the NEHRA and P.L.101-614

NEP Strategic Objectives

Reduce the:

- Loss of life
- Number and severity of casualties
- Property loss
- Social disruption
- Adverse impact on the natural environment

NEP Office Objectives

- Represent federal earthquake risk reduction efforts
- Increase awareness of and support for NEP
- Improve planning for earthquake risk reduction
- Improve the transfer of earthquake risk reduction knowledge
- Facilitate implementation of earthquake risk reduction measures
- Evaluate program effectiveness

NEP Interagency Working Group Objectives

- Improve the integration of earthquake-related activities of the federal agencies
- Provide means of communicating with their stakeholders
- Improve earthquake risk reduction efforts carried out by state and local governments and the private sector

NEP Objectives for Each Agency

- Carry out programmatic responsibilities
- Support NEP
- Carry out earthquake Executive Orders

NEP Activities

- Monthly coordination meetings
- Strategic planning
- Recommend program priorities
- Consolidation of annual budget
- Fulfill biennial reporting requirements

NEP and NEHRP have Common Elements

- Fundamental objectives are nearly identical
- FEMA serves as the lead agency of both
- FEMA, USGS, NIST and NSF have key roles in both
- State and local governments and the private sector are key to achieving objectives of both

NEHRP is Statutory

- Establishes the national policy objective to "*...reduce the risks to life and property from future earthquakes in the United States...*"
- Establishes a program for earthquake risk reduction
- Authorizes activities by FEMA, USGS, NSF and NIST
- Appropriates funds
- Establishes the Interagency Coordinating Committee
- Calls for programmatic plans and reports

NEP is Administrative

- NEP increases the effectiveness of NEHRP
  - » Incorporates a larger number of agencies
  - » Recognizes importance of additional federal earthquake activities
  - » Addresses integration of earthquake into programs
  - » Calls for strategic planning
  - » Calls for research priorities
- NEP encourages knowledge implementation

NEP is Administrative (cont'd.)

- NEP addresses the need for agencies to work together
  - » Addresses the need to eliminate redundancy
  - » Calls for budget coordination
- NEP calls for policy advocacy and incentives
- NEP calls for increased mitigation
- NEP has an advisory working group
- NEP is broad and encompasses NEHRP

Will NEP replace NEHRP?

- Perhaps
- Will take legislation
- Congress will "wait and see"

How do NEP and NEHRP relate to the National Mitigation Strategy?

- The NMS is a statement of policy: Make mitigation the core of national disaster policy
- NMS is broad, it will influence all FEMA programs
- It includes all natural and technological hazard programs
- It affects all response and recovery programs
- It affects federal insurance programs and policy
- It affects training and planning efforts
- NEP is the embodiment of the NMS for earthquakes

NEP

Other Federal Agencies		**NEHRP**
DOD/USACE	OSTP	FEMA
GSA	DOE	DOI/USGS
EPA	DOT	NSF
NASA	HHS	DOC/NIST
DOC/NOAA	HUD	
NRC	VA	

Marketing Challenges

- Acknowledgment of risk
- Acceptance of responsibility
- Appropriate action

Marketing Approaches

- One size fits all
- Smorgasbord
- Context

Distribution of Effort

- To eat an elephant....
- Capitalize on relative strengths
- GPRA

NEHRA Amended (Public Law 101-614)

- Defined specific responsibilities for each Program agency
- Required Advisory Committee to be established
- Established post-earthquake investigations program in USGS
- Increased authorized budgetary levels over the 3-year period

Updated goals of P.L. 101-614 include:

- Increase earthquake education
- Develop improved design and construction techniques
- Implement system to predict and characterize EQs and their effects
- Develop model building codes and land use practices
- Research our ability to deal with earthquakes
- Apply research results
- Assure availability of earthquake insurance

MISSOURI DEPARTMENT OF TRANSPORTATION

EARTHQUAKE RESPONSE PLAN

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ABSTRACT

This presentation will be a brief overview of the preparedness and actions the personnel of MoDOT will take in the event of a major earthquake.

Discussion will center around activating and mobilizing field and office personnel to respond to the damaged areas. Identification of the three staging areas and why they were chosen along with the initial plan of action to inspect the roadways and structures on the two primary routes which will serve St. Louis and our Southeast (Bootheel) area. Other priority routes will be identified to provide access to these two areas.

Use of other state forces for bridge inspection, road and bridge repair, and traffic diversion will also be presented including traffic control once highways are available. Review of the other three modes of transportation and the potential effects of a major earthquake and their ability to provide assistance.

Because of the probable effect of a major earthquake on employees in the areas most likely affected, discussion of training, mentor program, and incorporation of the individual district action plans will be reviewed. The assumption that has been made is that for some undetermined length of time our employees will not be available in the work force.

Finally, MoDOT's interaction with the Southeastern Regional Emergency Management Assistance Compact (SREMAC) will be discussed.

Missouri Department of Transportation
Earthquake Response Plan
Support Center

I. STATEMENT OF PURPOSE

The primary mission of the Missouri Department of Transportation (MoDOT) in the event of a catastrophic earthquake is to provide manpower, equipment, and the necessary material to ensure the operational capabilities of a transportation system into and out of the area affected by the earthquake.

II. SITUATION AND ASSUMPTIONS

A. Situation: Earthquake Disaster

There is an high possibility of widespread damage and loss of life if a major earthquake occurs within the New Madrid seismic zone in Southeast Missouri. It is also recognized that an earthquake may occur with little or no warning.

B. Assumptions: Earthquake Disaster

1. A major earthquake in the New Madrid seismic zone would affect large areas of eastern and southern Missouri, as well as the states of Indiana, Illinois, Tennessee, Kentucky, Arkansas and Mississippi.

2. The scale and scope of a major earthquake similar to the ones that occurred during 1811 and 1812 would be catastrophic and require detailed advance planning.

3. The damage occurring from a catastrophic earthquake would affect the state's transportation system causing damage to roadways, bridges and support equipment.

4. MoDOT's planning is based on the effects of an earthquake measuring 7.6 on the Richter Scale, which is the standard used by the State Emergency Management Agency (SEMA) for a major earthquake. Because of the damage an earthquake of this magnitude would cause, the plan does not include use of employees from districts 6 and 10 in the early stages (these workers would have more immediate family concerns).

However, this plan is designed to be flexible enough to use even in less catastrophic scenarios. In a smaller earthquake more local resources may be available. Response may be best suited for the district level, or perhaps only portions of this plan will be appropriate. The level of response will be determined by the Assistant Chief Engineer-Operations.

III. ORGANIZATION

A. General

1. The Governor has been given the ultimate responsibility for emergency management activities in the state. When the Governor declares that a state of emergency or earthquake disaster exists within the state, he may delegate authority to the Adjutant General who may provide for the subdelegation of the authority for overall coordination and control of disaster relief operations to the Director, State Emergency Management Agency, who will exercise control of disaster relief operations through the personnel and facilities of the State Emergency Operations Center (SEOC).

2. The Missouri Department of Transportation (MoDOT's) Chief Engineer will be the individual with responsibility and authority to activate the MoDOT Earthquake Emergency Response Plan when called upon by the Governor or his authorized representative.

3. Upon order to activate the MoDOT Earthquake Emergency Response Plan, the Chief Engineer will establish and provide staffing to the State Emergency Operations Center (State EOC), the Missouri Department of Transportation (MoDOT) Support Center EOC, the State Emergency Operations District (SEOD) EOC, the Missouri Department of Transportation (MoDOT) District EOC, and the Missouri Department of Transportation (MoDOT) Assembly Area EOCs.

The following MoDOT personnel will be assigned the responsibility of staffing and operational control of the Emergency Operations Centers (EOCs):

a. State EOC (SEMA headquarters in Jefferson City) - Assistant Chief Engineer-Operations
b. MoDOT Support Center EOC - Deputy Chief Engineer
c. SEOD EOC (SEMA district field office) - MoDOT District Engineers
d. MoDOT District EOC (district office) - District Operations Engineer
e. MoDOT Assembly Areas EOC (see Attachment 5a) - Maintenance Liaison Engineers and District Area Engineers

(See Attachment 1 for organizational block diagram.)
(See Attachment 4 for additional staff assignments from designated MoDOT Earthquake Response Personnel and each Division's Responsibilities.)

4. In the event the District Engineer and the District Management Team are unable to staff the various EOCs within the disaster area, the Deputy Chief Engineer shall assign personnel to staff the EOCs.

B. Earthquake Emergency Operations Interaction

Upon declaration of an earthquake emergency by the Governor, the MoDOT section of the State EOC will coordinate with the MoDOT Support Center EOC to begin assembling personnel, equipment and material for movement to designated assembly areas. The control and movement of the personnel, equipment and materials will be directed by the MoDOT Assembly Area EOC until closure of the personnel, equipment and supplies in the assembly area. Upon closure in the Assembly Area, the manpower, equipment and material command and control will transfer to the MoDOT District EOC for future operations.

C. Coordination with Other Agencies

1. MoDOT has been assigned primary responsibility for the transportation function. The following agencies have been assigned support roles under this function: Missouri Army National Guard, Office of Administration, Department of Conservation, Missouri State Highway

Patrol, Department of Public Safety (Adjutant General), Missouri State Water Patrol, Department of Corrections, Department of Economic Development (Division of Transportation), Department of Natural Resources (Division of Parks, Recreation and Historic Preservation), Missouri Volunteer Organizations Active in Disasters, and Federal Agencies. Reference Missouri (SEOP), pages 28-31.

2. Coordination with other agencies shall occur at all levels of EOCs. When conflicts occur, the conflict will be forwarded to the next higher level EOC.

If the conflict cannot be resolved below the State EOC level, the State EOC (MoDOT Deputy Chief Engineer) shall resolve the conflict for the department.

3. In the event that MoDOT manpower, equipment and material is insufficient for the emergency, the MoDOT District Engineers will have authority to negotiate and enter into contracts with contractors for manpower, equipment and materials as required. (See Attachment 12 for a List of Prime Contractors) Also refer to RSMo 44.100 for emergency powers of Governor. (See Attachment 13 for "Chapter 44, Revised Missouri Statutes".)

4. In the event that the state and local resources are depleted, federal agency assistance may be requested. Congress authorized in Title 23, United States Code, Section 125, a special program from the Highway Trust Fund for the repair or reconstruction of federal-aid highways and federal roads which have suffered serious damage as a result of (1) natural disasters, or (2) catastrophic failures from an external cause. This program that is commonly referred to as the Emergency Relief, or ER, program and is administered by the Federal Highway Administration (FHWA), supplements the commitment of resources by states, their political subdivisions or other federal agencies to help pay for unusually heavy expenses resulting from extraordinary conditions. Thus, to obtain ER program funds for assistance in repairing earthquake damage on federal-aid highways, MoDOT must request assistance from FHWA.

Damage to highway facilities that are neither federal-aid highways nor federal roads may be eligible for other federal funds authorized by the Stafford Act, P.L. 93-288 and administered by the Federal Emergency Management Agency (FEMA). Federal agency assistance that may be available through FEMA may be requested by SEMA from the State Emergency Operations Center (SEOC) to FEMA Region VII, which will contact individual federal agencies from which assistance is requested.

The Assistant Chief Engineer-Operations will coordinate these activities with the assistance of the Maintenance Division.

For natural disasters, coordination among federal agencies is handled through an interagency agreement among the FEMA and the 11 federal agencies involved with hazard mitigation. Hazard mitigation teams are activated by these federal agencies immediately following a disaster.

For more information, guidance and instructions on the FHWA Emergency Relief program and procedures for requesting, obtaining and administering ER funds, see Attachment 8.

5. In the event that MoDOT manpower, equipment or material is required outside the boundaries of the State of Missouri, authority may be granted by the Deputy Chief Engineer to pass operational control to the requesting agency. Also refer to the multi-state, Interstate Earthquake Compact. (RSMo 256.155)

D. MoDOT Coordination

1. When the Governor declares that the earthquake emergency is over, the State EOC will notify the MoDOT Support Center EOC and SEOD EOC; in turn, the MoDOT Assembly Area EOC will be notified of the cessation of the emergency. Upon release of the manpower,

equipment and materials from the assembly areas, command and control will revert to each home MoDOT District EOC.

IV. LOGISTICS

A. Damage Assessment

1. Upon declaration of an earthquake emergency by the governor and subsequent establishment and staffing of the State EOC, SEOD EOC and the MoDOT EOC, the Deputy Chief Engineer will immediately mobilize all district alert forces and available field bridge inspection personnel for the purpose of assessing the condition of the highways and bridges on the State highway system. The first priority of the bridge inspection personnel will be to inspect all major river crossings within the disaster area, followed by other major bridges along the earthquake emergency highway routes. (For a List of Missouri and Mississippi River Bridges see Attachment 14). (For maps showing Pre-selected Priority Routes see Attachment 9). (For lists of bridges on priority routes to the St. Louis Area, information about those bridges, county maps showing the locations of those bridges, Missouri Maps showing 1st, 2nd,3rd and 4th priority routes to the St. Louis Area and to the Southeast Missouri Area and Area Engineer Locations, Names and Telephone Numbers see Attachment 10).

Each district and division shall maintain a list of all available bridge inspection personnel and provide this list to the Assistant Division Engineer-Bridge Maintenance, at the end of the off-system bridge inspections each year. Bridge inspection personnel are listed by District and Division in Attachment 2. A list of consultants that can provide detailed bridge inspection will be maintained by the Assistant Division Engineer - Bridge Maintenance. This listing shall include a section on inspectors that are certified for underwater inspections.

2. Immediate aerial surveillance will be flown over each preselected route into the affected area by MoDOT and/or other available aircraft. Aerial photographs of each bridge along the route will be taken and forwarded to the MoDOT Support Center EOC for review by the Deputy Chief Engineer and staff. Then, to facilitate the collection and analysis of all damage information, all reports must be forwarded to the SEOC immediately for processing and dissemination. See Attachment 9 for preselected priority routes. Also refer to VI (Operations) A and B.

Note: In the event that Federal Agency assistance is or may be requested for the repair or reconstruction of federal-aid highways from FHWA or for the repair or reconstruction of other highways through FEMA, it is required that the field surveys be made in cooperation with FHWA and FEMA. Also, it is required that the field report and subsequent reports document the damage. Pictures showing the kinds and extent of damage and sketch maps detailing the damage areas should be included in the field report to FHWA. For more information on the FHWA Emergency Relief (ER) Program, see Attachment 8.

3. The Deputy Chief Engineer shall consult MoDOT bridge maps, aerial photographs, and other available information, to determine the routes upon which MoDOT forces will concentrate efforts. MoDOT bridge maps are included in Attachment 3.

4. Transportation for bridge inspection personnel will be provided, as far as possible, by MoDOT vehicles. When MoDOT vehicles are no longer adequate, the Deputy Chief Engineer shall coordinate with support agencies, as per the State Emergency Operation Plan (SEOP) for procurement of support vehicles. Note: The Missouri Army National Guard (MOANG) agreed in a meeting with MoDOT , SEMA and other agencies on September 21, 1997 that they will provide the helicopters to transport MoDOT Bridge Inspectors to inspect routes and bridges; and will revise MOANG's "Emergency Response Operations Plan" to state this. Also, the Civil Air Patrol (CAP), an auxiliary of the U.S. Air Force, has agreed to provide aerial surveillance and communications relay over Southeast Missouri. The CAP has several fixed-wing aircraft, but no helicopters.

Air traffic separation and coordination is essential. The assigned altitudes will be from 0 to 1000 feet for helicopters and 1500 feet and above for fixed wing aircraft. SEMA will request that the airspace be closed by the FAA immediately following an earthquake. Flight authorization in the damaged area will come from the SEOC. Ingress/Egress routes are set along major highways. Inbound flights will stay on the South/West side of the route; outbound flights will stay on the North/East side of the routes. Communications between aircraft and between aircraft and the ground will be established on predesignated frequencies. This basically covers aircraft operations during the first 12 hours following a catastrophic earthquake. These procedures, however, will continue to provide aircraft safety and eliminate communication problems as follow-on and emergent aircraft missions are assigned. If necessary, the Deputy Chief Engineer may enlist the services of the Governor's office under RSMo 44.100 for the seizure of appropriate methods of transporting bridge inspection personnel. These methods may include, but will not be limited to; aircraft, boats, four-wheel drive and all-terrain vehicles.

B. Assembly Areas

1. Upon receipt of field reports from the bridge inspection teams, the Deputy Chief Engineer will contact the unaffected MoDOT District EOCs to obtain needed equipment, personnel, and material and dispatch them to appropriate assembly areas. A list of MoDOT personnel is included in Attachment 4. In addition, he will select the Assembly Area EOC Directors and will provide them with information regarding the personnel and equipment under their direction and the routes upon which they will concentrate. A list of possible assembly areas is included in Attachment 5. (See Attachment 5a for maps showing locations of pre-selected Assembly Areas.)

2. The Assembly Area EOC shall report to the SEOD EOC and the SEMA EOC concerning site conditions and progress. Assembly Area EOC Directors shall be responsible for keeping accurate records of personnel and equipment assignments for those items under their direction.

Note: See Attachment 8 for a "Detailed Damage Inspection Report" that is to be completed by MoDOT as part of the requirements for obtaining federal funds from FHWA for the repair and reconstruction of federal-aid highways.

3. Should field conditions warrant a move to a more desirable location, the Assembly Area EOC Director may change the location of the assembly area by coordination with the SEOD EOC.

C. Equipment

1. A comprehensive list of specialized equipment, including, but not limited to, dozers, motorgraders, trucks, backhoes, loaders, draglines, excavators and compressors, shall be maintained by the Director of the MoDOT Division of General Services and is included in Attachment 6. Each MoDOT District Engineer will maintain a current listing of contractors that may be called on to furnish heavy equipment through lease or rental, with a copy of the listing made available to the MoDOT Support Center EOC. (See Attachment 12 for a list of prime contractors.)

2. Support for equipment in the affected area, including fuel, lubricants, tools, and spare parts, will be shipped to the assembly areas as requested by the Assembly Area EOC from the unaffected MoDOT Districts. Forward refueling bases need to be established as quickly as possible to maximize flight time in the impacted zones. The Missouri Army National Guard will consolidate and coordinate the aircraft fuel requirements of the various aircraft used. Where this is not a viable alternative, the MoDOT District Engineer shall have authority to negotiate and enter into a contract with local suppliers for the necessary provisions. In addition, the State EOC may request assistance from the Governor's office under RSMo 44.100 for the seizure of necessary fuel, lubricants, tools, and spare parts.

3. Repair and servicing of equipment shall be the responsibility of MoDOT district field and shop mechanics assigned to the Assembly Area EOC.

D. System Repair Supplies

1. A comprehensive list of all specialized bridge repair supplies shall be maintained by the Assistant Division Engineer-Bridge Maintenance and is included in Attachment 7. A list of temporary steel and box girder bridges shall be maintained by the Division Engineer-Bridge and is also included as part of Attachment 7.

2. In addition to existing MoDOT surface repair supplies, a list of suppliers of surface repair material, including, but not limited to, aggregate, asphalt, concrete, corrugated metal pipe, etc., shall be maintained by each MoDOT District Engineer. This list is also available through the MoDOT Materials Division in the MoDOT Support Center. In addition, each MoDOT District Engineer will maintain a current listing of metal and concrete pipe that is stored at various MoDOT maintenance facilities.

E. Impediment Removal on Priority Routes

MoDOT will be responsible for the removal of traffic obstacles from all state highways which are designated priority routes. Impediment removal is the responsibility of the nearest Assembly Area EOC. City and county officials may also request MoDOT assistance through SEMA. SEMA will request assistance from the MoDOT representative in the SEOC.

F. Personnel Support Facilities

1. Where personnel support facilities are not available from other agencies but where such facilities exist in the form of hotels and restaurants on the fringe of the affected area, the Assembly Area EOC Directors will be authorized to purchase blocks of rooms and meals for the personnel under their direction with a field purchase order. See V. (Administration) E.

2. If necessary, the Deputy Chief Engineer may enlist the assistance of the Governor's office under RSMo 44.100 for the seizure of private facilities such as motor homes, campers, privately owned buildings, etc., as required for the billeting of personnel.

G. Medical Support

In the case of minor injuries incurred during the emergency, initial first aid will be administered by MoDOT personnel trained in CPR or first aid. In the case of major illness or injury, contact the nearest MoDOT assembly area to request emergency medical assistance.

V. <u>ADMINISTRATION</u>

A. Financing shall be from MoDOT funds, supplemented by funds as provided by RSMo 44.028 and 44.032.

<u>Note:</u> See Attachment 8 for information, guidance and instructions on the FHWA Emergency Relief (ER) program and procedures for requesting, obtaining and administering ER funds for the repair or reconstruction of federal-aid highways. Damage to other highways that are neither federal-aid highways nor federal roads may be eligible for other federal funds administered by FEMA.

B. All charges for labor, equipment rental and materials will be made to Function 604 and the following appropriate AFE:

1. Work on the state highway system - AFE Prefix 3 - Roadway Groups A, B, C, X, L, H, S, R, U, and F.

2. Work within the state, but not on the state highway system - AFE Prefix 3 - Roadway Groups M or N.

3. Work outside the state under mutual aid agreements - AFE Prefix 3 - Roadway Group T.

C. Records of accomplishment, employee work hours, equipment usage petroleum usage and material usage shall be kept by field crews and MoDOT Assembly Area EOC Directors in accordance with existing department policies. See Attachment 11 for guidelines for recording information. Attachment 11 should be forwarded to Business And Benefits Support Division weekly marked "Emergency Documents."

D. Temporary maintenance employees may be hired as necessary at wage rates and benefits under existing department policies by District Engineers, Assembly Area Coordinators or Area Engineers.

E. Local purchases may be made by field purchase order (form E-66), limited to $1,000 per project as per RSMo 44.032.10, and shall be subject to price controls as provided by RSMo 44.100.1(4)(d). Purchases up to $25,000 may be authorized by the Assembly Area EOC Director or their supervisor using a district purchase order (form E-100). The $25,000 limit may be waived by the Assistant Chief Engineer-Operations or his backup at SEMA, or by the Deputy Chief Engineer.

F. The requirement of determining local prevailing wage rates for contracted work shall be waived.

G. Personnel Administration

1. Personnel shall report to assigned work areas as directed. Any previously approved vacation or compensatory time off may be canceled.

2. Failure to report to assigned work areas may be cause for disciplinary action. Consideration may be given to cases of extreme personal emergency, such as critical illness in the immediate family, or severe loss of property due to the earthquake.

3. Personnel are subject to normal work policies, including, but not limited to, working hours, overtime, expenses and disciplinary action.

4. Where possible, personnel should be relieved from emergency duty periodically so as to minimize the length of the period of relocation.

5. Employees may designate that their paycheck be forwarded to a location of their choice. If no designation is made, the paycheck shall be handled consistent with current MoDOT policy.

H. Employee Support

1. Employees that have been temporarily reassigned to work in the disaster area may be away from their normal work group and families for an extended period of time. (See Attachment 15, "Guide for Staff Assigned to Disaster Operations") (See Attachment 16 for "EOC Provisions")

2. Each District Engineer and Division head shall appoint a contact person familiar with employee records to serve as an employee mentor. These mentors will be available to provide assistance for families and employees affected by the reassignment, such as providing information to the families about the MoDOT employees and other information that will assist the families with their needs.

3. Mentors should coordinate their efforts with each division and district and keep the employees informed of where their families can call or go to for the purposes of making contact.

VI. OPERATIONS

A. Primary Routing

Based on the assumption that an earthquake of severe magnitude occurs in the New Madrid fault area, aerial reconnaissance will begin immediately on preselected routes into the damaged area. State highway maps indicating these preselected routes are included in Attachment 9.

B. Aerial Reconnaissance, Damage Assessment and Movement of Forces to Assembly Area EOCs.

General:

Immediately upon declaration of an earthquake emergency, the MoDOT aircraft with photographic equipment and personnel will begin aerial reconnaissance of the preselected routes. This aerial reconnaissance will consist of low-level photographs of each bridge on the preselected route and any other section along the route that appears to have sustained damage. These aerial photographs, along with any other information obtained that is considered pertinent to the investigation, will be immediately returned to the MoDOT Support Center EOC for review and assessment. The MoDOT Support Center EOC will select primary and alternate routes for further detailed investigation by on-site field bridge inspectors. These field bridge inspectors will be dispatched by either radio-equipped MoDOT vehicles or by helicopter support furnished by other state or federal agencies. As bridges along the preselected routes are investigated, the details of damage and availability for use of the bridge shall be immediately reported to the MoDOT Support Center EOC. This reporting will be by county, route, and bridge number. This information will be used by the MoDOT Support Center EOC to establish the best routing available for insertion of field repair crews into the damage area.

Concurrently with the aerial and ground surveillance and detailed field bridge inspection of the possible routing to the damaged area, district field forces will be placed on alert for possible movement to designated MoDOT Assembly Area EOCs. This alert will consist of marshaling the necessary manpower, equipment and supplies in preparation for movement to the damaged area. The MoDOT Support Center EOC will notify each MoDOT District EOC and SEOD EOC of the movement order, routing and MoDOT Assembly Area EOC as the final destination.

Upon receipt of a movement order, district field forces will proceed to their assigned MoDOT Assembly Area EOC and, upon arrival, will report to the director of the MoDOT Assembly Area EOC. This report will include, but not be limited to, personnel by name and job title, equipment by type and MoDOT number, and materials available at the time of arrival.

<u>Phase One (Initial Inspection Phase and Critical Information Gathering of Priority Routes)</u>

In the event of a major earthquake, MoDOT employees with the following job titles must report As Soon As Possible to their normal work station:

- current and former Support Center bridge inspectors
- photolab photographers
- airplane pilots (report to the Jefferson City airport)
- Liaison Engineers (of the Maintenance, Traffic, Construction, Design and Bridge Divisions)
- assistant division engineer-bridge maintenance (to coordinate bridge inspection)
- bridge inspection technicians

- car dispatcher (of the General Services Division)
- bridge maintenance clerk and secretary
- Division Directors for Maintenance, General Services, Traffic, Construction and Bridge Divisions

Note: See Attachment 4 for MoDOT Earthquake Response Personnel and their Responsibilities.

In addition, each district must immediately staff and activate its emergency operations center and establish communication with the Support Center in Jefferson City.

Districts 1, 4 and 7 shall detour traffic that is eastbound into Missouri from states west and north of Missouri to the north through northern Missouri and /or Iowa to keep them out of the areas damaged by the earthquake, which would be primarily Districts 6 and 10. Districts 1, 4 and 7 shall detour this traffic northward over Routes 71, I-29 and I-35 into Iowa, where they could then go east on Route I-80, or at least northward to Missouri's Route 36, east on Route 36 to Macon and then north on Route 63 into Iowa if the Mississippi River bridge at Hannibal is closed.

The Assistant Chief Engineer - Operations shall report what planes are available. The Assistant Division Engineer - Bridge Maintenance shall assign inspectors and instruct them to go to the Jefferson City airport for aerial inspections of priority routes. The Photolab coordinator shall do the same for photographers. Photographers may use still cameras and/or video cameras. (See Attachment 9 for pre-selected priority routes.)

The Bridge maintenance clerk and/or secretary shall verify the satisfactory operation of all radio towers immediately and if one or more are not responding, shall investigate possible causes and solutions to make repairs.

The Car dispatcher shall immediately provide three radio-equipped vehicles. One vehicle will be for two bridge inspectors and two liaison engineers. The inspectors will immediately begin inspection of the Route 50-44-100 priority route from Jefferson City to St. Louis, and the liaison engineers shall be dropped off at St. Clair to staff the Assembly Area EOC. They shall go as far as possible on Route 100, then backtrack to determine the best route from Route 100 to the St. Louis-Lambert Airport. Heading north from Route 100 onto Route 340, then north on Lindbergh to the airport appears to have the fewest obstacles. Once the best route has been determined and communicated to the Assembly Area EOC, it becomes the priority route to the airport from Route 100.

A second vehicle shall take two liaison engineers to staff the Wentzville Assembly Area EOC and two inspectors to inspect the Route 54-70 priority route to the St. Louis-Lambert Airport from Jefferson City. If I-70 is blocked, detour to the north in St. Charles and take the 370-270-67 priority route from Jefferson City to Wentzville and then to the airport.

A third vehicle shall take two inspectors south along Routes 63 and 60 to inspect the priority route to Willow Springs and Van Buren Assembly Area EOC from Jefferson City.

The National Guard has agreed to provide two helicopters with pilots waiting at the Jefferson City airport that are designated for MoDOT use. One shall carry two inspectors and one liaison engineer along Routes 63 and 60 to inspect that route to the Van Buren Assembly Area EOC. There, the liaison engineer will help staff the EOC and the inspectors will then drive east as far as possible to inspect Route 60. The Support Center EOC radio operator will confirm with District 9 at Willow Springs that radio-equipped vehicles will be waiting at the Van Buren Assembly Area for bridge inspectors flying there.

The second helicopter shall carry four bridge inspectors along the priority Routes of 50, I-44, and 100 to the St. Louis area. Two inspectors shall be dropped off at Park Hills, where a vehicle shall be waiting to take them north to inspect Route 67. The vehicle shall be made available by the Regional Maintenance Building at Farmington at an agreed upon meeting place in Park Hills. The other two bridge inspectors will stay with the helicopter for stop-and-go inspections in the St. Louis area as directed by the St. Clair and/or Wentzville EOC's.

District 9 staff shall immediately travel to the Van Buren Maintenance Building to staff an EOC. Combined with the vehicle traveling Routes 63 and 60 from Jefferson City, this will confirm the availability of the Route 63-60 priority route to near the edge of the affected area of Southeast Missouri.

A MoDOT plane will carry one bridge inspector and one photographer to determine and document the status of Route 50-44-100 from Jefferson City to Downtown St. Louis.

The Rolla Area Engineer shall immediately drive east as far as possible on I-44 to inspect that route and its bridges.

All of the above workers must stay in frequent radio contact with the Assembly Area EOCs that they are assigned to as work progresses.

Phase Two (Opening Major Emergency Routes)

By this time, SEMA will be in continuous contact with the Support Center EOC which will have established radio or telephone contact with each district's EOC.

Each district EOC will have workers and resources standing by and prepared to travel as requests for assistance are received from the SC EOC.

District 6 Field EOC/Assembly Areas will be set up at St. Clair and Wentzville. District 10's Field EOC/Assembly Area will also be activated at Van Buren by District 9 personnel. These locations may be changed if more suitable locations are available.

Requests for MoDOT assistance will be received at SEMA's EOC. The requests will be relayed to the Support Center (SC) EOC, which will contact the appropriate district. The district will deploy the needed resources and make work assignments. If more resources are needed, the Assembly Area EOC will contact the SC EOC, who will determine other sources.

When the work is completed, the Assembly Area EOC will notify the SC EOC. All completed projects and deployed resources must be documented at the SEMA EOC in order to track available resources for their possible future use on other projects.

Since district offices in Districts 6 and 10 may not be available, requests for assistance in these areas will go to the Assembly Area EOCs. These EOCs will utilize the assistance of Area Engineers from Districts 6 and 10, who will be available by this time, as well as work crews and equipment that have arrived from other districts.

As District 6 and 10 employees become available for duty they will report to the nearest maintenance building or project office, then contact the nearest Assembly Area EOC to report their availability for work.

C. Organization of MoDOT Assembly Area EOC

1. The MoDOT Assembly Area EOC directors will assume command and control of all personnel, equipment and material upon arrival at the MoDOT Assembly Area EOC and will be responsible to the SEMA district field office for coordination and control of all field crews assigned to that MoDOT Assembly Area EOC. The size and structure of each field crew will be determined by their assigned duties. Specific personnel, by name, will be placed in charge of each

individual field crew. Each individual field crew will be assigned a specific job duty to include location, priority of work and probable emergency repairs required. Coordination between Assembly Area EOCs and field crew supervisors will normally be by MoDOT radio or other means of communication that may be available. Each field supervisor will be expected to report damage assessment and repairs accomplished at least twice daily, as this information will be necessary to maintain current situation maps in the SEMA disrict field office (and the State EOC, if possible).

2. Personnel

a. Volunteer - Volunteer personnel may be utilized at the discretion of the MoDOT Assembly Area EOC Director and may either be incorporated individually into MoDOT crews, or assigned specific tasks to be performed as a group. Volunteers will be issued, and required to use, standard MoDOT safety equipment (i.e. vests, hard hats, etc.) where applicable.

b. Temporary - Temporary employees may be obtained by contract per III-(Organization) C.3. of this document, or may be hired per V-(Administration) D. of this document. All temporary employees will be considered "wage only" employees and will be subject to all existing MoDOT rules, regulations and procedures for such employees. The duration of the temporary positions will be at the discretion of the MoDOT Assembly Area EOC Director.

D. Repairs

The MoDOT Assembly Area EOC Directors, in coordination with the Support Center EOC, shall determine the extent of the repairs to be completed under emergency conditions and shall use damage assessment reports to determine the priority and scheduling of repairs.

E. Traffic Control and Security

Traffic control and security within the damage area is the primary responsibility of all law enforcement agencies, but MoDOT personnel may be assigned short-term traffic control responsibilities. Assembly Area EOC Directors shall determine needs for detours, bypasses, etc. to ensure usability of priority routes. Traffic control in MoDOT work areas is the responsibility of the MoDOT field crews. Additional traffic control requirements and security will be requested through the SEMA district field office as needed.

F. Oversize/Overweight Vehicle Route Clearance Program

MoDOT's Motor Carrier Services' Unit staff will coordinate an oversize/overweight vehicle route-clearance program for the movement of large equipment. This action will be focused upon delivering needed machinery or other commodities that exceed normal size and weight to emergency sites.

The Motor Carrier Services Administrator, or his backup, will be stationed at the SEMA EOC to gather overweight/overdimension travel requests. These will be radioed to the Motor Carrier Services office for route clearance. When the best route is determined it will be radioed back to SEMA; this communication will replace the standard paper documents.

VII. COMMUNICATIONS

Since an earthquake of severe magnitude will probably disrupt all means of communication, primary communication will be with the MoDOT radio system. The MoDOT radio system is a high band mobile relay radio system composed of a number of district control stations, field base stations, mobile relays/repeaters and mobile units. Eight frequencies are used in the system. Separate transmit and receive frequencies are assigned to each of three channels- Channel A, Channel B and Channel C. The seventh frequency, along with the mobile radio transmit frequency assigned to Channel A, are used to form the St. Louis metro channel. Likewise, the eighth frequency, along with the mobile radio transmit frequency assigned to Channel B, are used to form the Kansas City metro channel.

A. The districts will install temporary power poles as needed to maintain temporary communications, until towers are put back up. A radio antenna can be put on top of each one of the temporary power poles for communication.

B. Maximum use of the multi-channel, MoDOT radio system will be made by field repair crews. Since field repair crews may be using equipment from different districts, the multi-channel radio system will allow intercommunication. Each one of MoDOT's ten districts operates within the radio system on one of three channels. Channel A is assigned to Districts 1, 5, 7 and 10; Channel B is assigned to Districts 2, 6 and 8; and Channel C is assigned to Districts 3, 4 and 9. The radio system utilizes mobile repeaters/relays to repeat (re-transmit) all signals transmitted by mobile units, field base stations or district control stations. This process strengthens the signal, thus extending the talking range of the mobile, field base stations and district control stations.

The licenses for these radios, with maximum of 100-watt output, is issued to MoDOT by the Federal Communications Commission (FCC). MoDOT's Support Center keeps a permanent file of these licenses with copies issued to the districts.

There are several tower locations with repeaters/relays and/or district control stations at various places throughout Missouri. To talk to the repeaters or district control stations, the person has to tune his radio to the channel for the repeater at the tower in the area where he wants to talk. In order to talk to another district, such as District 6, from Jefferson City, we would use the District 5 control station to talk to an intermediate repeater/relay, which can talk to the District 6 control station The district control stations are either located at, or connected to, the district office; sometimes using microwave links and sometimes using direct phone lines. Microwave links are point to point communications; therefore alignment of the antennas at the tower locations is critical and very vulnerable to earthquake damage. Each of the radio towers has a portable power generator that can be used to provide power to the district control stations and/or repeaters/relays at the tower when the regular power supply has failed.

Communication by cell phones is very difficult during an emergency because so many people try to use cell phones at the same time that the cell phone system gets overloaded. MoDOT has no proprietary rights or privileges, in the event of an emergency, to public cellular service. An alternate, almost sure way of communicating, is to use mobile radios in cars spaced at intervals of 10 to 50 miles apart and these mobile car radios will relay messages back and forth between Jefferson City and the disaster area (St. Louis Area or Southeast Missouri Area) from car to car. The spacing of car radios depends on the atmospheric conditions that day as well as the terrain, so the spacing of cars has to be determined by trial.

C. Secondary communication networks may be utilized as they become available for use. Such networks may include the Missouri State Highway Patrol, National Guard, ham amateur radios, Civil Air Patrol, CB's and privately owned networks.

Also, the MoDOT radios in the Support Center and the district offices shall be staffed. Available telephone capability in MoDOT facilities will be used to supplement radio communications.

D. The MoDOT radio shall be staffed in the SEOC when needed. Reference Annex B - COMMUNICATIONS of the SEOP for additional information concerning communication facilities.

VIII. PUBLIC INFORMATION

Press releases and public information reports will be made by the SEMA Joint Public Information Center. All information for news releases will be developed jointly by representatives of the affected emergency organizations. The MoDOT information representative will be the Support Center Public Affairs Director or designated backup.

IX. EXTENDED OPERATIONS (24-HOUR OPERATIONS)

When it is foreseen that the need for extended operatiois imminent, tne individual exercising command and control over each area of operation, such as each Assembly Area and EOC, will declare the need to establish and implement a shift work schedule. Employees, as groups or as individuals, may be placed on eight or twelve hour shift schedules depending on the nature of the emergency staffing requirements or functional assignments.

X. MANUAL UPDATE

It shall be the responsibility of the Assistant Chief Engineer - Operations to keep this manual updated in the future, at least as frequently as on an annual basis, preferably on a continuous basis with some specific person assigned to perform this task as part of his or her regular job duties.

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NEW DEVELOPMENTS IN SEISMIC RISK ANALYSIS OF HIGHWAY SYSTEMS

by

Stuart D. Werner[1], Craig E. Taylor[2], James E. Moore II[3], Jon S. Walton[4], John B. Jernigan[5], and Howard H.M. Hwang[6]

ABSTRACT

This paper summarizes current research to develop a new seismic risk analysis (SRA) procedure for highway and roadway systems. The procedure synthesizes geoseismic, engineering, network, and economic models to assess earthquake effects on system-wide traffic flows and travel times. The SRA results provide an improved basis for prioritizing highway components for seismic retrofit, and for defining seismic performance requirements for these components.

1.0 INTRODUCTION

Past experience has shown that earthquake damage to highway components (e.g., bridges, roadways, tunnels, retaining walls, etc.) can severely disrupt traffic flows and this, in turn, can impact the economy of the region as well as post-earthquake emergency response and recovery. Furthermore, the extent of these impacts will depend not only on the seismic response characteristics of the individual components, but also on the characteristics of the highway system that contains these components. System characteristics that will affect post-earthquake traffic flows include: (a) the highway system network configuration; (b) locations, redundancies, and traffic capacities and volumes of the system's links between key origins and destinations; and (c) component locations within the links (e.g., Moore et al, 1997).

From this, it is evident that earthquake damage to certain components (e.g., those along important and non-redundant links within the system) will have a greater impact on the system performance (e.g., traffic flows) than will other components. Unfortunately, such system issues are typically ignored when specifying seismic performance requirements and design criteria for new and existing components; i.e., each component is usually treated as an individual entity only, without regard to how its damage may impact highway system performance. Furthermore, current criteria for prioritizing bridges for seismic retrofit represent the importance of the bridge as a traffic-carrying entity only by using average daily traffic count, detour length, and route type as parameters in the prioritization process. These criteria do not account for the systemic effects associated with the loss of a given bridge, or for combinatorial effects associated with the loss of other bridges in the highway system. However, consideration of these systemic and combinatorial effects can provide a much more rational basis for establishing seismic retrofit priorities and performance requirements for highway components.

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In recognition of these issues, the National Center for Earthquake Engineering Research (NCEER) has included system seismic risk analysis (SRA) in its current six-year seismic research project entitled "Seismic Vulnerability of Existing Highway Construction." This paper describes the SRA research being conducted under the NCEER project including: (a) a new SRA procedure that has been developed under the project; (b) an initial demonstration application of the procedure to the Memphis Tennessee highway system; (c) current research to further develop the procedure; and (d) the applicability of the procedure for real-time post-earthquake loss estimation.

2.0 SEISMIC RISK ANALYSIS PROCEDURE

2.1 General Description

The highway system SRA procedure is shown in Figure 1. It can be carried out for any number of scenario earthquakes and simulations, in which a "simulation" is defined as a complete set of system SRA results for one particular set of input parameters and model uncertainty parameters. The model and input parameters for one simulation may differ from those for other simulations because of random and systematic uncertainties (Werner et al., 1996).

For each earthquake and simulation, this multi-disciplinary procedure uses geoseismic, geotechnical and structural engineering, transportation network, and economic models to estimate: (a) earthquake effects on system-wide traffic flows (e.g., travel times, paths, and distances); (b) economic impacts of highway system damage (e.g., repair costs and costs of travel time delays); and (c) post-earthquake traffic flows along vital roadways (to facilitate emergency response planning). Key to this process is a modular GIS data base that contains the data and models needed to implement the system SRA.

This SRA procedure has several desirable features. First, it has a GIS framework, to enhance data management, analysis efficiency, and display of analysis results. Second, the GIS data base is modular, to facilitate the incorporation of improved data and models from future research efforts. Third, the procedure can develop aggregate SRA results that are either deterministic (consisting of a single simulation for one or a few scenario earthquakes) or probabilistic (consisting of many simulations and scenario earthquakes). This range of results facilitates the usefulness of SRA for a variety of applications (e.g., seismic retrofit prioritization and criteria, emergency response planning, planning of system expansions or enhancements, etc.). Finally, the procedure uses rapid engineering and network analysis procedures, to enhance its future use as a real-time predictor of system states and traffic impacts shortly after an actual earthquake.

2.2 GIS Data Base

The GIS data base contains four modules with data and models that characterize the system, seismic hazards, component vulnerabilities, and economic impacts of highway system damage. To facilitate analysis efficiency, these modules are pre-processors to the four-step SRA procedure shown in Figure 1.

2.2.1 System Module

The system module contains the following information to characterize the highway system, as provided by transportation and urban planning specialists:

- *System Data* – including: (a) system network configuration linkages, and component types and locations; (b) numbers of lanes, traffic flows, capacities, and congestion functions for each roadway link; (c) origin-destination zone locations and trip tables; and (d) any special system characteristics, such as certain roadways being critical for emergency response or national defense.

- *Traffic Management* – including measures by transportation officials for modifying the system to ease post-earthquake traffic flows (e.g., detour routes, changing roadways from two-way to one-way traffic, etc.)

- *Transportation Network Analysis Procedures* – to estimate post-earthquake traffic flows for each simulation and scenario earthquake.

2.2.2 Hazards Module

The hazards module contains input data and models provided by geologists and geotechnical engineers for characterizing system-wide ground motion, liquefaction, landslide, and surface fault rupture hazards. Input data include: (a) the ensemble of scenario earthquake events developed during the initialization phase of the SRA (Sec. 3.1); (b) locations and topographic data for slopes within the system that could be prone to landslide; and (c) local soil conditions throughout the system, as needed to estimate local geologic effects on ground shaking and the potential for liquefaction and landslide. Models contained in the hazards module will estimate: (d) the attenuation of rock motions with increasing distance from the earthquake source, for a range of earthquake magnitudes; (e) the effects of local soil conditions on the motions at the ground surface; and (f) permanent ground displacements due to earthquake-induced landslide, liquefaction, and surface fault rupture. A deterministic representation of hazards models will use mean values of these quantities. A probabilistic representation will use probability distributions to account for uncertainties in the seismologic, geologic, and soil input parameters and in the hazard evaluation models.

2.2.3 Component Module

The component module contains input data and models provided by structural and geotechnical engineers to characterize each component using a "loss model" and a "functionality model". The loss model represents the component's direct losses (i.e., repair costs), and the functionality model represents its "traffic states" (i.e., whether the component will be partially or completely closed to traffic during the repair of the earthquake damage, the durations of these closures, and speed limits for traffic along the component during repair). Both models are a function of the level of ground shaking at the component's site, as well as the level of permanent ground displacement due to liquefaction, landslide, or surface fault rupture. The models for each component are developed by evaluating: (a) its seismic response to each designated level of ground shaking and permanent ground displacement; (b) its "damage state", (i.e., the degree, type, and locations of any earthquake damage to the component); (c) its damage repair procedures; and, from this (d) its traffic states at various times after the earthquake (to reflect the rate of traffic restoration as repairs proceed).

After each component's traffic states are obtained, they are incorporated into the highway system network model to obtain the "system state", i.e., the ability of each link in the system to carry traffic at various times after the earthquake (in terms of number of open lanes, speed limits, etc.). These system states will reflect the effect of each component's damage state on adjacent and underlying roadways. They will depend on the component's location in the system, as well as system network characteristics.

A deterministic representation of loss and functionality models will use mean values of the component repair costs and traffic states. A probabilistic representation will use probability distributions to account for uncertainties in the evaluation of the component seismic response, and in the estimation of the resulting repair costs and traffic states.

2.2.4 Socio-Economic Module

The socio-economic module contains models and data for evaluating broader social and economic impacts of earthquake-induced traffic flow disruptions. These impacts can include indirect dollar losses (e.g., to commuters and businesses), effects on emergency response (e.g., reduced access to medical, police, fire-fighting, airport, government centers, etc.), and societal effects (e.g., reduced access to residential areas, shopping areas, etc.). This module is developed by transportation specialists, urban planners, and economists.

2.3 Analysis Procedure

2.3.1 Step 1: Initialization of Analysis

The initialization of the SRA (Step 1) contains two parts. First, regional earthquake source models are used to define an ensemble of scenario earthquakes, in which each earthquake is most commonly defined in terms of its magnitude, location, and frequency of occurrence. Uncertainties in defining the values of the various earthquake input parameters may also be modeled at this stage. The second part of Step 1 establishes the total number of simulations for each scenario earthquake, as further described in Werner et al. (1996).

2.3.2 Step 2: Development of Each Simulation for Each Scenario Earthquake

Under Step 2, the following evaluations are carried out to develop each of the simulations for each scenario earthquake:

- *Hazard Evaluation.* First, the data and models contained in the hazards module are used to estimate the earthquake ground motions and geologic hazards throughout the system.

- *Direct Loss and System State Evaluation.* Once the hazards are estimated, the data and models from the component module are used to evaluate direct losses and system states (defined at various times after the earthquake).

- *Traffic Flow Evaluation.* The system data and transportation network analysis procedure from the system module are applied to the pre-earthquake system and post-earthquake system states, to assess earthquake effects on system-wide travel times, travel distances, and travel paths, as well as traffic flows along roadways vital to emergency response.

- *Socio-Economic Impact Evaluation.* Once the earthquake effects on traffic flows within the system are evaluated, the data and models from the socio-economic module are used to evaluate impacts of the impeded traffic flows in terms of: (a) indirect dollar losses; and (b) reduced access to and from emergency response centers.

2.3.3 Step 3: Incrementation of Simulations and Scenario Earthquakes

Under Step 3, the evaluations from Step 2 are repeated, in order to develop multiple simulations for multiple scenario earthquakes (if the SRA is to be probabilistic).

2.3.4 Step 4: Aggregate System Analysis Results

This final step in the SRA process is carried out after the system analyses for all simulations and scenario earthquakes have been completed. In this step, the results from all simulations and earthquakes are aggregated and displayed. Depending on user needs, these aggregations could focus on the seismic risks associated with the total system or with individual components. Furthermore, the system or component results could be provided: (a) for individual simulations, which is termed a seismic vulnerability analysis, and/or (b) for the broader (probabilistic) range of simulations, leading either to loss statistics (e.g., average annualized loss) or to loss distributions that show the severity of earthquake-induced system losses for different probability levels[7]. For research purposes, the impacts of incorporating uncertainties into the SRA will be of considerable interest. For other purposes, such as the planning of seismic strengthening programs for existing highway systems, outputs can be adapted and/or simplified to meet the particular requirements of each user audience.

3.0 DEMONSTRATION ANALYSIS

3.1 Objective and Scope

Early in the NCEER Highway Project, the SRA procedure was used with then-available data and models to carry out a demonstration SRA of the Memphis, Tennessee highway-roadway system (Fig. 2). The objective of the analysis was to: (a) illustrate the applicability of the SRA procedure; and (b) provide a basis for prioritizing research needs to improve the procedure. Because of limitations in many of the then-available data and models, the results from this analysis are preliminary. This analysis is described in more detail by Werner and Taylor (1995 and 1996).

3.2 Assumptions

The Memphis highway-roadway system is shown in Figure 2. This SRA consisted of deterministic analysis of the response of this system to four different earthquakes (Fig. 3a). This paper presents results from one of these earthquakes, termed Earthquake D, which has a moment magnitude of 5.5 and is centered 35 km to the north of the city of Memphis. Assumptions for this SRA are summarized below.

3.2.1 System Input Data

The system's network configuration was obtained from the University of Memphis. Traffic data and O-D zones within the system were provided by the Memphis and Shelby County Office of Planning and Development (OPD). The traffic flow data were from their 1988 traffic forecasting model.

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[7]The "loss" can be defined in several ways, such as direct repair cost, travel time delays due to earthquake damage (between certain key origin-destination zones or aggregated over all zones), indirect losses due to travel time delays, or other adverse consequences.

3.2.2 Network Analysis Procedure

The MINUTP traffic forecasting software (Comsis, 1994) was used to analyze pre- and post-earthquake traffic flows. This software was chosen because it is used at the Memphis-Shelby County OPD, and all regional traffic data were available in the input format for this software. MINUTP is based on the Urban Transportation Planning System (UTPS), which was developed over two decades ago by the U.S. Dept. of Transportation (see Sec. 4.5.1). Also, the then-available version of MINUTP was not GIS-compatible, which increased the effort needed for our system analysis.

3.2.3 Seismic Hazards

The system-wide ground shaking due to Earthquake D was represented in terms of peak ground acceleration (PGA), and was based on soil conditions estimated from prior local geologic mapping by the University of Memphis (Fig. 3b). The PGA at each bridge site was estimated by: (a) using an early version of the Hwang and Huo (1997) attenuation equation to compute site-specific rock accelerations; and (b) applying Martin and Dobry (1994) soil amplification factors to these rock accelerations, to obtain corresponding ground surface PGAs that include effects of local soil conditions (Fig. 4).

3.2.4 Bridge Loss Models

Loss models previously developed under the ATC-25 project for conventional highway bridges were used to estimate direct losses for each bridge in the system (ATC, 1991). In these models, the direct losses depend only on whether the bridge has simple spans or is continuous/monolithic; i.e., other bridge structural attributes that could impact seismic performance are not considered.

3.2.5 Bridge Functionality Models

Functionality models for this demonstration SRA represented bridge traffic states as the number of lanes open at discrete times after an earthquake, as a function of PGA and the original number of lanes along the bridge. They were developed by modifying ATC-25 bridge restoration models based on prior observations of the seismic performance and repair and reconstruction processes for California bridges during the Loma Prieta and Northridge Earthquakes (Werner and Taylor, 1995). Two different models were developed in accordance with the ATC-25 conventional highway bridge designations -- one for simple-span bridges and one for continuous bridges. In addition, to illustrate effects of bridge damage repair rates on post-earthquake system performance, functionality models were developed for two discrete times -- three days and six months after the earthquake.

3.2.6 Economic Model

Studies of economic impacts of earthquake-induced highway system damage have shown that indirect dollar losses due to such damage can far exceed the direct losses for repair of the damage (e.g., Gordon and Richardson, 1996). However, methods for estimating such impacts for future earthquakes are not yet well developed. Therefore, for this demonstration SRA, a simplified procedure from BAA (1994) was used to estimate costs due to deterioration in commute time only. These cost estimates are based on vehicle-hours of delay (as obtained from the MINUTP system analyses), corresponding person-hours of delay (based on an assumed average vehicle occupancy rate of 1.4 persons/vehicle), truck-hours of delay (assuming 30 percent of the vehicles are trucks), and excess fuel costs due to travel time delays.

3.3 Results

3.3.1 Direct Losses

In accordance with the ATC-25 model used in this demonstration SRA, direct losses due to damage to the system's bridges are represented as a damage ratio, DMG (%), which is defined as the ratio of the repair cost for each bridge to its total replacement cost. For Earthquake D, the average damage ratio (averaged over all of the 286 bridges in the system) was 37.4%.

3.3.2 Travel Times and Distances

System State Results. Figure 5 shows the pre-earthquake system state and post-earthquake system states at times of three days and six months after Earthquake D. This figure indicates that, although Earthquake D has only a moderate magnitude ($M_W = 5.5$), its proximity to the northern segment of the Memphis highway system causes extensive roadway closures in that segment, with lesser impacts on other segments of the system.

Total System-Wide Travel Times. Table 1 contains the total pre- and post-earthquake travel times and distances for the Memphis highway system. This table shows that the modified system states due to Earthquake D result in a total system-wide travel time three days after the earthquake that is nearly 34 percent longer than the pre-earthquake values. At six months after the earthquake, the bridge repairs within that time have reduced the total travel time; however it is still nearly 20 percent longer than the pre-earthquake value.

Total System-Wide Travel Distances. Table 1 shows that the total system-wide travel distances at times of three days and six months after the occurrence of Earthquake D are not sensitive to the modified system states. This trend may be due to the significant loss of service along the faster but less direct highway segments at the north and northeastern portions of the beltway, because of the many damaged bridges along those segments. As a result, drivers would be forced to use ground surface routes with fewer damaged bridges that are shorter but slower than the beltway routes.

O-D Zone Travel Times. Table 2 shows that, at a time of three days after the earthquake, the travel times between the O-D zones listed in the table are, on the average, nearly 16 percent larger than those for the pre-earthquake system. The travel time increases are largest for northernmost of the highlighted zones, which are at Shelby Farms (Zones 249 and 252), Bartlett (Zone 264), and the Covington Pike (Zone 274). This is because, as previously noted, it is this section of the Memphis area highway and roadway system that is most severely damaged. At a time of 6 months after the earthquake, Table 2 shows that the travel times to and from these zones have been reduced substantially, and are now only 5.3 percent larger than the pre-earthquake values.

O-D Zone Travel Distances. The travel distances to and from the O-D zones listed in Table 2 are insensitive to system damage from Earthquake D (Werner and Taylor, 1995).

Economic Impacts. Estimates of economic impacts for times of both three days and six months after the earthquake are shown in Table 3. They are based on total system-wide travel time delays per 24-hour day of 126,000 vehicle-hours and 73,000 vehicle-hours at times of three days and six months after the earthquake respectively (as previously shown in Table 1). From this, the BAA (1994) cost estimation procedure leads to a total cost per day of the earthquake-induced time delays of \$1.6 million at three days after the earthquake, and \$930 thousand at six months after the earthquake. We then estimated the total time delay costs over a one-year time period after Earthquake D, by assuming an average daily time-delay cost for the year of \$930 thousand (which corresponds to the above daily cost at a time of six months after the earthquake). From this, the total cost of the system-wide time delays over this one-year time period was computed to be 365 days x \$930,000 = \$340 x 10^6.

4.0 NEW DEVELOPMENTS

Since the above demonstration SRA was completed, we have implemented significant improvements to the SRA procedure. This improved procedure has just been used in a probabilistic re-analysis of the seismic risks to the Shelby County, Tennessee highway-roadway system, which includes the city of Memphis. This new analysis is described in Werner et al. (1998).

The improvements to the SRA procedure include upgraded models for: (a) multiple scenario earthquakes; (b) ground shaking and liquefaction hazards; (c) bridge vulnerability modeling; and (d) transportation network analysis. They are summarized in the remainder of this section.

4.1 Scenario Earthquakes

In a SRA of a system with spatially dispersed components, individual scenarios are required to evaluate correlation effects of earthquakes, i.e., the simultaneous effects (including systemic consequences of damages) of individual earthquakes on components located at diverse sites. For our updated SRA of the Memphis highway system, we have adapted scenario earthquake models for the Central and Eastern United States (CEUS) that were developed by Frankel et al. (1996) as part of the United States Geological Survey (USGS) National Hazard Mapping Program. For other regions of the United States, Frankel et al. models for those regions (or other appropriate models that account for regional seismologic and geologic characteristics) should be similarly adapted.

The Frankel et al. work for the CEUS uses four different spatially smoothed models based on historical seismicity data, plus a special model for the New Madrid Seismic Zone (NMSZ). Our adaptation of these models is summarized in Sections 4.1.1 and 4.1.2.

4.1.1 Historical Seismicity Models

For developing scenario earthquakes for our SRA of the Memphis highway-roadway system, we define a large seismicity zone around Memphis that extends from 88.0 to 92.0 degrees longitude and from 34.0 to 38.0 degrees latitude. This zone (denoted as Zone A) has been divided into 1,763 microzones, with dimensions of about 11.1 km in both length and width.

Three different models are weighted to establish the earthquake activity within each microzone, based on historical seismicity data from a USGS catalogue that is an updated and improved version of the Seeber-Armbruster (1991) earthquake catalogue. These models are developed from earthquakes with the following magnitude cutoffs and completeness times: (1) magnitude 3+ earthquakes since 1924; (2) magnitude 4+ earthquakes since 1860; and (3) magnitude 5+ earthquakes since 1700. In addition, a fourth model by Frankel et al. that represents background seismicity over al larger zone was weighted with the above three models to establish earthquake activities. This larger zone (denoted as Zone B) extends form –80.0 to –112.0 degrees longitude and from 30.0 to 40.0 degrees latitude.

The number of earthquakes shown in the USGS catalog to exceed the respective minimum magnitude of Models 1 through 3 respectively is counted and, based on the starting and end date of the model (e.g., 71 years for Model 1), is converted to a frequency of occurrence. As work progressed, Frankel et al. overrode these estimates within a special aerial zone (denoted as Zone C) that covers about 20 percent of Zone A. For microzones within Zone C, frequencies of earthquake occurrence were established by assuming that the earthquakes from the historic seismicity model for this zone are uniformly distributed throughout the zone.

To account for uncertainties in the locations of earthquakes estimated for each of the 1,763 microzones in Zone A, a relatively flat gaussian model is applied that redistributes and smooths the earthquake locations among the microzones. Given this redistribution of earthquake occurrences for each of Models 1-3, and assuming a threshold magnitude of 5.0 for the onset of earthquake damage, a "b" value of 0.95 in the Richter magnitude-frequency relationship (derived elsewhere) is used to estimate the frequency of occurrence of earthquakes with magnitude ≥ 5.0 in each microzone (for each of these models). For Model 4, a uniform distribution is used to allocate potential earthquakes with magnitudes ≥ 5.0 among all of the microzones.

Based on a method of adaptive weighting, the four above-mentioned models are combined to derive frequencies of occurrence of earthquakes of magnitude ≥ 5.0 in each microzone. Next, these frequencies are summed to determine the corresponding frequency of occurrence within the overall seismicity zone. Using this frequency and the frequencies in each microzone, a conditional cumulative probability matrix is then developed for the overall seismicity zone. This two-column matrix contains microzones (numbered) in one column, and cumulative conditional probabilities (from 0 to 1) in the other column. In addition, a Poisson model is used to convert the frequency of occurrence of earthquakes with magnitudes ≥ 5.0 in the overall seismicity zone to a corresponding probability of occurrence.

At this stage, a natural way to develop these scenarios for purposes of analyzing system performance and for eventually compiling information on loss distributions and their variability over a time dimension is to employ a "walk-through" analysis. (Daykin et al., 1994). The first step in this analysis selects an appropriate time frame over which the analysis would be carried out (e.g., one or more time frames of 10 years, 50 years, 100 years, etc.). Then, for each year in each time frame (starting with Year 1 and then repeating the process for each successive year), successive uniform random number generators are applied with the appropriate cumulative conditional probability distribution to evaluate: (a) whether at least one earthquake of magnitude ≥ 5.0 has occurred somewhere in the large seismicity zone during the year; (b) if so, whether a second earthquake has occurred in the zone during the year; and (c) for each earthquake that has occurred in the zone during the year, the microzone where the earthquake is located. We also use a random generation technique to estimate the earthquake magnitude, with the likelihood of diverse magnitude levels assumed to be represented by a Richter (lognormal) magnitude-recurrence relationship.

4.1.2 New Madrid Fault Zone

The modeling the New Madrid fault zone involves the following steps: (a) modification of the Der Kiureghian et al. (1977) approach to distribute earthquake occurrences within the fault zone; (b) use of estimates of the frequency of occurrence for earthquakes in the zone based on the Frankel et. al. approach and other relevant studies (e.g., Johnston, 1996; Johnston and Schweig, 1996; Crone, 1998); use of a Poisson model to convert these frequencies to probabilities of occurrence; and (c) postulation that the fault zone is comprised of four parallel linear faults.

Following this, a walk-through analysis is used to develop a random sequence of earthquakes occurring within the zone during the time period of interest. To illustrate, let us assume that the probability of occurrence of an earthquake with a given magnitude (say magnitude 8.0) within the New Madrid fault zone is 0.002. From this, the walk-through process for each year involves the use of successive random number generators to indicate: (a) whether an earthquake of this magnitude has occurred within the fault zone (by checking whether the random number has a value $\leq$ 0.002); and (b) if so, which of the four fault traces is the source of the earthquake. Then, subsequent steps involve: (c) estimation of the rupture length along the fault trace, by first using the Wells-Coppersmith (1994) relationship between rupture length and earthquake magnitude to obtain best estimate rupture lengths, and then by accounting for uncertainties in this relationship through use of the polar method in log space (Law and Kelton, 1991) with a standard deviation of 0.22; and (d) estimation of the location of the rupture length within the overall fault trace, by applying a random number generator to the difference between the fault trace and the estimated rupture length[8].

The results of this walk-through analysis of earthquakes occurring within the New Madrid fault zone are combined with the results of the walk-though analysis of potential earthquakes from the historical seismicity models (Sec. 4.1.1) to estimate the total earthquake activity during each year of the time frame of interest.

4.1.3 Results

The above approach has been used to develop an ensemble of 2,320 earthquakes with moment magnitudes that range from 5.0 to 8.0 and occur within the above-indicated zones that surround Memphis and Shelby County, Tennessee. This is further described in Werner et al. (1998).

4.2 Ground Motion Hazards

The ground motion hazards used in the new SRA of the Shelby County highway-roadway system are represented as peak ground accelerations (PGAs) at the ground surface. The estimation of these PGAs for a particular site involves: (a) use of a rock motion attenuation relationship to estimate bedrock peak acceleration levels; and (b) application of soil amplification factors to these rock accelerations, to develop corresponding PGAs at the ground surface that incorporate effects of local soil conditions. When new bridge vulnerability models are incorporated into the SRA procedure during this year (1999), ground motion hazards will be represented as five-percent damped spectral accelerations, rather than PGAs.

In the new SRA of the Shelby County highway-roadway system, we use: (a) the Hwang and Huo (1997) rock motion attenuation relationships for peak acceleration and for spectral accelerations over a wide range of natural periods; and (b) the Hwang et al. (1997) soil amplification factors for NEHRP site classifications A through E. These procedures have the following benefits: (a) they are internally consistent, i.e., they are intended for use together to compute ground surface peak accelerations and spectral accelerations (as the product of the Hwang and Huo rock motions and the Hwang et al. soil amplification factors); (b) they specifically focus on anticipated CEUS ground shaking characteristics; (c) the Hwang and Huo rock motion

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[8] In this, the difference between the rupture length and the total length of the fault is computed, and a uniform random number generator is used to indicate where the fault rupture is initiated relative to one end of the fault trace.

attenuation relationships compare well with other well-established relationships for the CEUS; (d) the Hwang et al. soil amplification factors are developed from state-of-the-practice analytical procedures; and (e) effects of uncertainties in various input parameters are considered.

4.3 Liquefaction Hazards

The treatment of liquefaction hazards within the multi-scenario framework of the SRA procedure involves the following steps: (a) compilation of soils data for the region; (b) for a given scenario earthquake and simulation, evaluation of the potential for liquefaction throughout the highway-roadway system, including estimation of permanent ground displacements; and (c) estimation of traffic states at bridges and along roadways within the system due to these ground displacements. Our plans for carrying out these steps in our SRA procedure are summarized below.

4.3.1 Soils Data

The first step in the characterization of system-wide liquefaction hazards is, of course, to compile appropriate soils data throughout the highway-roadway system. For Shelby County, such data have been compiled by the Center for Earthquake Research and Information (CERI) of the University of Memphis, from 8,500 boring logs throughout the county (Ng et al., 1989). In this, the county is divided into a series of cells with dimensions of about 2,500 ft. by 3,000 ft. Then, the data from the boring logs are used to develop the following information for those cells where boring logs are available: (a) estimated average values SPT blowcounts, natural soil density, and unconfined compressive strength for each soil layer, as well as ground surface elevation, and groundwater level; and (b) development of a representative soil log for the cell. For those cells, where no data are available, soil properties are estimated using data from the nearest cells with soils of the same geologic unit (Hwang and Lin, 1997).

A GIS data base containing these data has been made available by CERI for use in our SRA of the Memphis highway-roadway system. An update of this data base is reportedly underway and nearing completion (for release during early 1999).

4.3.2 Hazard Evaluation Procedure

Evaluation of liquefaction hazards throughout the highway-roadway system will follow the approach by Youd (1998). Our adaptation of this approach (see Werner et. al., 1998) consists of the following steps:

- *Initial Screening.* An initial screening of soils and geologic is carried out (as a pre-processor to the actual SRA) to initially establish which sites in the system have a low potential for liquefaction and therefore can be eliminated from further analysis. For the SRA of the Shelby County highway-roadway system, these initial screening efforts are guided by prior liquefaction evaluations of the Memphis area by Hwang and Lin (1997).

- *Further Screening.* For those sites shown by the initial screening to have a potential for liquefaction, further screening is carried out through simplified and conservative assessment of the range of possible ground shaking hazards at each site along the highway-roadway system due to each given scenario earthquake. Sites that are thereby shown to have a low liquefaction potential are eliminated from further evaluation for that earthquake.

- *Seed-Idriss Procedure.* For those sites that are still shown to have a potential for liquefaction, the Seed-Idriss (1982) procedure is used to compute factors of safety against liquefaction at each site for each scenario earthquake.

- *Permanent Ground Displacement.* For the sites shown from the above step to have a factor of safety against liquefaction that is less than 1.0, permanent ground displacements are estimated as follows: (a) for bridge or roadway sites with gently sloping ground or a free face condition, the Bartlett-Youd (1995) procedure is used to estimate lateral spread displacements; and (b) the Tokimatsu-Seed (1987) procedure is used to estimate vertical settlements.

4.4 Bridge Modeling

4.4.1 Background

The estimation of bridge damage states and traffic states is an essential step in the SRA process. This section describes bridge models that are currently used in the SRA process for this purpose, or are planned for use in the future.

This SRA procedure will incorporate a default method for rapid analysis of bridge damage states due to ground shaking that is named the rapid pushover method (Dutta and Mander, 1998). This procedure has the following features: (a) it provides rapid estimation of bridge damage states, and is therefore practical for application to the large numbers of bridges that will be involved in SRA of highway-roadway systems; (b) it is a simplified but rational engineering procedure based on capacity-demand spectrum-analysis and pushover-analysis concepts; and (c) it uses readily available information on each bridge that is contained in the NBI data base, in order to infer input parameters needed for the damage state evaluation.

The focus of the rapid pushover method is to carry out rapid analysis of large numbers of bridges in a highway-roadway system. As a result, the method contains certain simplifications for representing the distributions, types, and locations of damage throughout a bridge. Although these simplifications will be of only secondary importance for most bridges, they could be more important for certain special bridges whose performance could have a significant impact on overall highway-roadway system performance (e.g., major bridges located along highway segments with limited or no redundancy).

Because of this, the SRA procedure will provide the user with an option of directly specifying alternative damage state fragility curves that would be independently developed using detailed analysis methods deemed appropriate by the user. However, the application of such methods will invariably be time consuming. Therefore, the methods will be impractical for application to many bridges, and should be applied only to limited numbers of special bridges that may be encountered.

4.4.2 Rapid Pushover Method

The rapid pushover method involves the development of a capacity spectrum, a demand spectrum, and the resulting damage state fragility curves. This process is summarized in the following subsections (Dutta and Mander, 1998).

4.4.2.1 Capacity Spectrum

The bridge capacity spectrum for the onset of each damage state is computed as the sum of the capacity contributions of the piers and the three-dimensional arching action of the deck.

- *Pier Contribution to Bridge Capacity.* Under longitudinal or transverse excitation, the strength capacity of a bridge pier will usually decay as the earthquake shaking proceeds. The magnitude and rate of this decay will depend on the design details at or near the potential plastic hinge zones -- particularly connection details such as lap splices and anchorage zones -- and on the shear capacity of the columns and the column-to-cap connections. Although sophisticated energy-based evaluation techniques are available for evaluating these sources of strength decay, a more simplified displacement-based method of analysis is instead used, in order to increase the speed and efficiency of the evaluation process. This method uses a simplified strength degradation model for the bridge pier, in which the total pier capacity consists of: (a) diagonal strut (or arch) action which constitutes the concrete resistance; and (b) resistance contributions arising from the longitudinal and transverse reinforcing steel. These contributions to the pier capacity are expressed in terms of geometric factors alone, which can be obtained or inferred from the NBI data base (FHWA, 1995b).

- *Deck Contribution to Bridge Capacity.* The contribution of the deck to the bridge's total base shear capacity is overlooked in most capacity analyses. This contribution is due to the resistance of the deck resulting from plastic moments that are mobilized by the bearings working as a group. This action occurs because, as the deck rotates, lateral displacement also occurs which is resisted by frictional forces in each bearing and by membrane action in the deck when the span gap closes. Dutta and Mander (1998) have evaluated this effect for bridges with multiple simply-supported spans and with continuous spans. For these cases, a plastic mechanism analysis is used to establish the deck capacity as the lowest capacity of all possible postulated failure mechanisms. These failure mechanisms incorporate the geometry of the deck spans, the relative flexibility of the pier bents, and the resistance and capacities of the bearings.

4.4.2.2 Demand Spectrum

A simplified form of the each bridge's demand spectrum for each scenario earthquake and simulation is constructed by: (a) representing the bridge's demand spectrum by a short-period segment with a constant spectral acceleration, and a long-period segment that is inversely proportional to the natural period; and (b) anchoring the short-period and long-period segments of the spectrum to site-specific spectral accelerations at periods of 0.3 sec. and 1.0 sec. respectively. In this, the site-specific spectral accelerations for a damping ratio of five-percent of critical are obtained from the ground motion model contained in the Hazards Module.

4.4.2.3 Fragility Curves for "Standardized" Bridges

Median values of spectral acceleration (at a period of 1.0 sec.) that lead to the onset of each of five specified damage states are developed for a series of "standardized" bridges, which are defined in Basoz and Mander (1998) as corresponding to "long" bridges with "no appreciable three-dimensional effects". For each damage state, this process involves: (a) computing an effective damping ratio from specified deformation levels for the onset of the given damage state; (b) modifying the five-percent-damped demand spectrum obtained from the ground motion model to correspond to this effective damping ratio; (c) obtaining a median spectral acceleration for the particular damage state and standardized bridge type, by scaling the modified demand spectrum until it intersects the capacity spectrum at the deformation level corresponding to the onset of the given damage state; and (d) obtaining a corresponding fragility curve by assuming that uncertainties associated with the method of analysis and with randomness of material properties are lognormally distributed with specified standard deviations.

4.4.2.4 Fragility Curves for Specific Bridge in Highway-Roadway System

For a specific bridge within the highway-roadway system, the fragility curve is developed by: (a) selecting the appropriate standardized bridge type for that bridge; and (b) modifying the fragility curve for the standardized bridge to account for effects of three-dimensional arching action in the deck and effects of skew, which are estimated from geometric parameters available in the NBI data base.

4.4.3 Other Damage State Models

Development of the rapid pushover method has been ongoing throughout this past year of the Highway Project. As a result, it is not yet incorporated into the SRA procedure, and alternative procedures have been used to carry out the new SRA of the Shelby County highway system that is described in Werner et al. (1998). These procedures are summarized below..

- *Typical Bridges in Shelby County.* Jernigan (1998) recently used the capacity-demand method described in the FHWA (1995a) seismic retrofit manual in order to develop damage state fragility curves for the 452 bridges within the Shelby County highway-roadway system, Tennessee. This work involved development of a GIS data base of structural attributes for these bridges, grouping of bridges according to superstructure and substructure characteristics, and development of fragility curves for each grouping that establish the probability of achieving none/minor, repairable, or significant damage as a function of peak ground acceleration (ATC, 1996). Dynamic analysis was used to develop the demands for bridges within each group, whose attributes are selected from random sampling of the range of attributes for that group. This approach was used to develop fragility curves for six bridge groups that typify nearly all of the bridges in Shelby County.

- *Major Bridges in Shelby County.* The Shelby County highway-roadway system contains two large steel bridges that cross the Mississippi River along Interstate Highways 40 and 55. For these bridges, special evaluations were conducted to develop bridge damage states, corresponding traffic states and repair costs, and resulting fragility curves. The fragility curves for the Mississippi River crossing along Interstate 40 was based on prior seismic analyses of each segment of the bridge that were conducted as part of a current seismic retrofit of the bridge (IAI, 1993). For the Mississippi River crossing along Interstate 55, experience and judgement were used to estimate the fragility curves for each damage state. The development of the fragility curves for each of these major bridges is described in Werner et al. (1998).

4.4.4 Traffic States

An important step in the bridge modeling process is the establishment of traffic states along the roadways at each end of the bridge, and also along roadways that pass beneath the bridge. These traffic states represent the ability of the various roadways to carry traffic, in terms of the number of lanes that remain open to traffic and possibly any reduction in speed limit as well. Once the traffic states are established for a given scenario earthquake and simulation, they are incorporated into a system network model to establish overall post-earthquake system states. Transportation network analysis procedures are then applied to these system states to estimate earthquake effects on system-wide traffic flows (see Section 4.5).

These traffic states will vary with time after the earthquake, to reflect the estimated rate and type of post-earthquake repair of the bridge. This rate of repair will, in turn, depend not only on the type and extent of damage to the bridge, but also on construction practices within the region of the country that contains the highway system being analyzed. To account for these variables when establishing improved bridge models for our updated SRA of the Shelby County roadway system, we proceeded as follows: (a) a series of damage state definitions was established for the various bridges in the system; (b) experienced bridge engineers from the Memphis area and the Tennessee Department of Transportation reviewed these damage states and provided their opinion as to the costs, types, durations, and traffic impacts associated with the repair process for each damage state; (c) similar reviews were conducted by experienced engineers from the California Department of Transportation who were involved in repairs of bridges damaged during the Loma Prieta and Northridge Earthquakes; (d) from this, interim models were established that provide repair costs and traffic states (at various times after the earthquake) for each bridge damage state; and (e) these models were incorporated into the component module for the SRA procedure, as default traffic states for bridges and roadways subjected to ground shaking and ground displacement hazards.

4.5 Transportation Network Analysis Procedure

4.5.1 Background

As previously noted, the network analysis portion of our prior demonstration SRA of the Memphis highway system relied on MINUTP -- a standard program that implements Urban Transportation Planning System (UTPS) algorithms (Werner et al., 1996). Experience from that analysis showed that data preparation and implementation of MINUTP was unacceptably time consuming – partially due to the fact that MINUTP was not GIS-compatible. Also, although UTPS models and their derivatives are standard planning tools in cities receiving Federal support for local transportation projects, such models have the following deficiencies for SRA applications: (a) consideration of an adequate level of detail for representing the region served by the system (i.e., region boundaries, O-D zones, and the system network structure) is costly; (b) loss-of-service measures developed from UTPS network assignment models are inconsistent with loss-of-service measures from other UTPS models; (c) behavioral shifts due to major disasters such as large earthquakes are difficult to represent; and (d) the UTPS procedure has little capacity for considering time dependence of system performance characteristics.

In view of this, it became clear that an alternative transportation network analysis procedure was needed that: (a) provides a capacity for more rapid estimation of network flows; (b) represents the latest well-developed technology and circumvents technical limitations of the UTPS algorithms; (c) is compatible with the GIS-based framework of our current SRA procedure; and (d) provides a capability for using transportation system input data typically available from Metropolitan Planning Organizations (MPOs).

We have found that a new Associative Memory (AM) procedure for rapid estimation of traffic flows that was developed at the University of Southern California (USC) best meets the above objectives (Moore et al., 1997). The objective of this AM work has been to provide rapid and dependable estimates of flows in congested networks, given changes in link configuration due to earthquake damage, and to attach these changes to the decision-making procedures used to prioritize bridges for seismic retrofit. Such a procedure articulates well with existing efforts in the field, because these flow estimates are input to both total transportation system cost and accessibility measures.

4.5.2 Overview of AM Procedure

The AM procedure is derived from the artificial intelligence field to predict changes in highway system flows. These predictions are based on good approximate solutions to constrained optimization problems that represent the economic determinants of network flows. As such, the AM procedure has the capability to determine changes in the system's total commuting time due to changes in the highway system network. To illustrate, if one link of a freeway is being considered for retrofit, the change in the total system commuting time due to removal of this link is calculated by the following steps: (a) identification of equilibrium flows and commuting times for each link in the intact (pre-earthquake) network; (b) calculation of total system commuting times by summing the commuting times for all links; (c) removal of the link from the highway system, simulating closure due to earthquake damage; and (d) determination of the change in total system commuting time due to the link's removal.

4.5.3 Development of AM Matrix

The AM procedure focuses on the development of an AM matrix that is used to map given sets of system network configurations (stimulus) to lead to corresponding traffic flows (response). The AM matrix is developed from the following steps:

- *Step 1. Training and Test Cases.* Standard numerical analysis is used to develop an ensemble of user equilibrium traffic flows for various network configurations, all of which represent the same general type of network and traffic flow characteristics. Most of these solutions are designated as training cases, with the remainder designated as test cases. These flows are computed for each link in the system in terms of equivalent passenger-car-units per hour.

- *Step 2, AM Training.* The training cases from Step 1 are used to train the AM; i.e., to determine the elements of the AM matrix that minimize the mean-square difference between the true user equilibrium traffic flows for all training cases and the estimated flows using the AM matrix.

- *Step 3. AM Testing.* The basic premise of this approach is that the AM matrix will provide a good estimate of traffic flows from other network configurations that represent similar conditions to those of the training cases, but have not been included in these cases. To check this, the AM matrix is used to predict traffic flows for each test case from Step 1, and these predicted flows are compared to the actual flows for the test cases as obtained during that step.

- *Step 4. AM Refinement.* From past experience, Step 3 will usually lead to excellent comparisons between predicted and actual traffic flows if an adequate number of training cases has been selected. However, if needed, additional training and test cases can be developed in Step 1 and used to further refine the AM matrix and the accuracy of its traffic flow predictions.

4.5.4 Current Status

We are continuing to refine the programming the AM procedure for rapid estimation of traffic flows, to minimize data storage requirements. This programming considers that the procedure has both training and stimulus-response sub-modules. The training sub-module solves conventional user-equilibrium flow problems given different configurations for the Memphis network. The stimulus-response sub-module constructs an AM matrix that best fits these user equilibrium inputs (network configurations) and outputs (traffic flows). In this way, the exact user-equilibrium solutions "train" the AM, which then can be used to obtain very rapid estimates of traffic flows for other network configurations not included in the training sub-module. These AMs have been shown to provide good approximations of user-equilibrium flows associated with new network configurations, including networks in which capacity has been lost.

Although creation of training data is a pre-processing step, users of the SRA methodology will also have the opportunity to use the training sub-module to solve for exact user-equilibrium flows for selected post-earthquake system states. Such solutions will be particularly beneficial if the user elects to show deterministic SRAs for a limited number of scenario earthquakes. In addition, even for probabilistic SRAs involving multiple scenario earthquakes and simulations, results from such exact solutions can usually be added to the training data provided to the stimulus-response sub-module.

5.0 ECONOMIC IMPACTS

Future development of the SRA procedure will include a major effort to incorporate improved models for estimating how damage to the highway-roadway system will affect the productivity of economic sectors in the surrounding region. This effort will consider that damage to buildings and contents will reduce the demand for transportation services. Damage to the highway-roadway network will reduce transportation supply. How the regional economy responds to these changes requires a detailed model that is disaggregate in terms of economic sectors as well as geographic space. Developing and packaging such a model is challenging. A sophisticated user interface is needed to link user needs with a set of interacting models and a substantial site-specific data bank. Such models should also include assessment of economic losers and gainers due to earthquake damage to the system, and due to policies implemented to mitigate this damage.

6.0 CONCLUDING COMMENTS

This paper has described a new SRA procedure for highway systems, a preliminary demonstration application of the procedure to the Memphis highway system, and new research that has dramatically improve the procedure and its highway-roadway system seismic performance results.

The principal benefit of the SRA procedure is its ability to directly represent seismic performance of highway systems – in terms of post-earthquake traffic flow – and to represent systemic effects associated with the damage to various highway components. This information will provide a much improved basis for decision-making pertaining to such issues as prioritizing various components for seismic strengthening, establishing component seismic performance requirements and design criteria, and justifying funding for seismic retrofit or other seismic risk reduction measures.

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TABLE 1. EFFECTS OF EARTHQUAKE D ON TOTAL SYSTEM TRAVEL TIMES AND DISTANCES

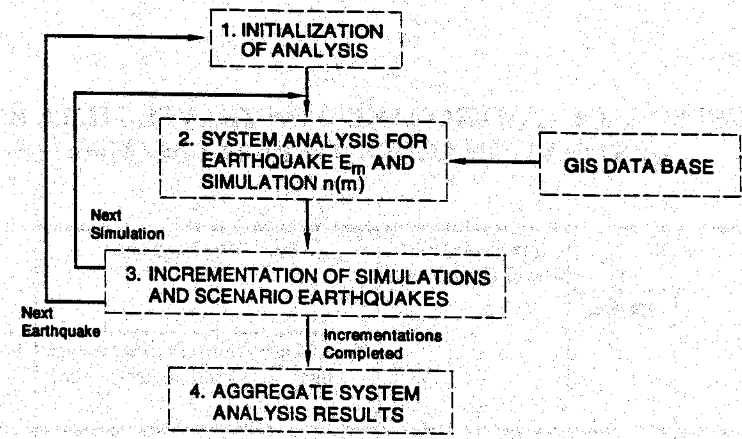
PARAMETER	PRE-EARTHQUAKE VALUE	TIME AFTER EARTHQUAKE = 3 DAYS		TIME AFTER EARTHQUAKE = 6 MONTHS	
		Value	Percent Increase over Pre-EQ	Value	Percent Increase over Pre-EQ
Total vehicle hours traveled over 24-hour period (incl. congestion)	3.73×10^5	4.99×10^5	33.8	4.46×10^5	19.6
Total travel distance (mi) over 24-hour period	15.5×10^6	15.6×10^6	small	15.6×10^6	small

TABLE 2. EFFECTS OF EARTHQUAKE D ON TRAVEL TIMES BETWEEN ORIGIN-DESTINATION ZONES (Over a 24-Hour Time Period)

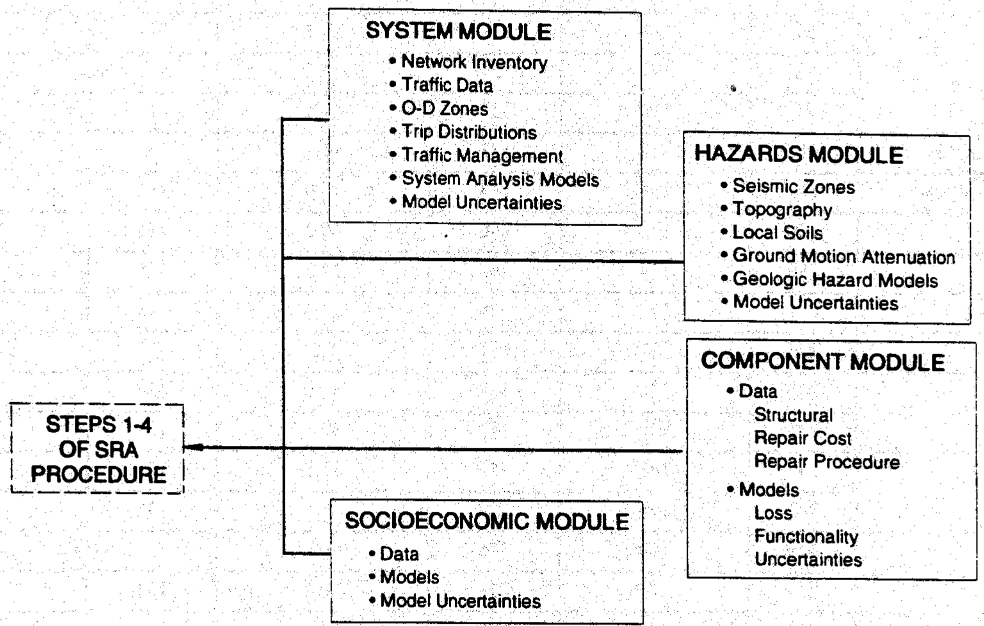
Origin-Destination Zone		Pre-Earthquake Travel Time (Hours)	3 Days After Earthquake		6 Months After Earthquake	
Description	Number		Travel Time (hrs)	Percent Increase over Pre-Earthquake Time	Travel Time (hrs)	Percent Increase over Pre-Earthquake Time
Government Center (downtown Memphis)	7	128	143	11.7	133	3.9
	8	122	141	15.6	130	6.6
Medical Center	25	122	136	11.5	127	4.1
	26	114	129	13.2	121	6.1
	27	114	129	13.2	121	6.1
	28	115	129	12.2	121	6.2
	29	119	133	11.8	124	4.2
University of Memphis	111	119	131	10.1	122	2.5
President's Island (Port)	151	138	153	10.9	144	4.3
Memphis Airport	188	136	150	10.3	142	4.4
Federal Express	189	130	145	11.5	136	4.6
Mall of Memphis	201	127	145	14.2	133	4.7
Hickory Hill	213	171	185	8.2	177	3.5
Poplar-Ridgeway	230	130	148	13.0	136	4.6
	231	130	147	13.1	136	4.6
Germantown	236	141	157	11.3	147	4.3
	241	176	187	6.3	181	2.8
Shelby Farms	249	169	176	4.1	174	3.0
	252	127	211	66.1	152	19.7
Bartlett	264	148	199	34.5	155	4.7
Covington Pike	274	137	181	32.1	151	10.2
	TOTALS	2813	3255	15.7	2963	5.3

TABLE 3. ECONOMIC IMPACTS OF TRAVEL TIME DELAYS DUE TO EARTHQUAKE D

Time After Earthquake	Time Delay (Vehicle-Hours/24-Hour Day)			Cost/Day
	Total	Non-Trucks	Trucks	
3 Days	126,000	88,200	37,800	$\$1.6 \times 10^6$
6 Months	73,000	51,100	21,900	$\$9.3 \times 10^5$

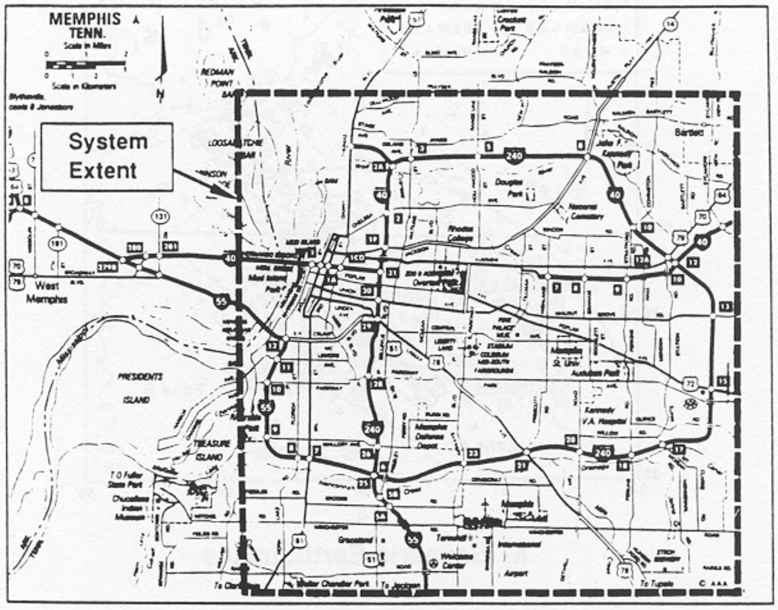


a) Overall Four-Step Procedure

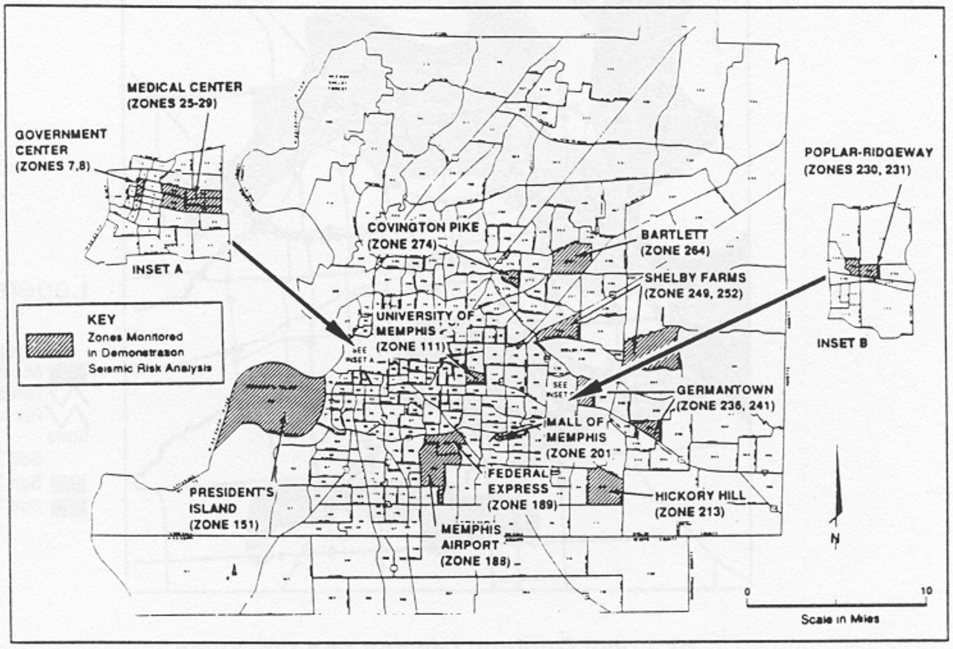


b) GIS Data Base

FIGURE 1. SRA PROCEDURE FOR HIGHWAY TRANSPORTATION SYSTEMS

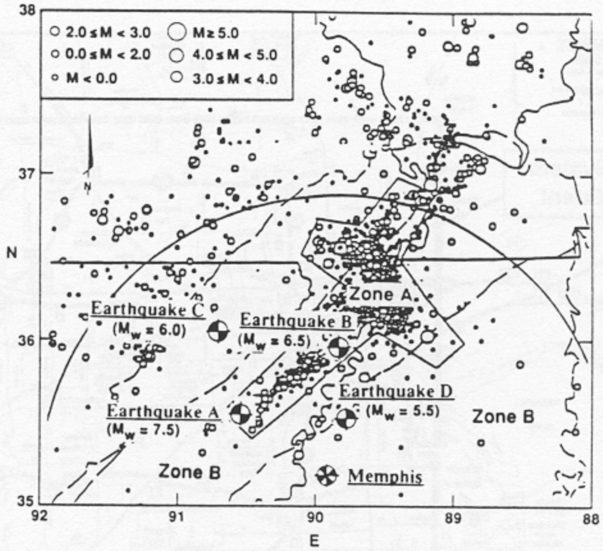


a) System Extent

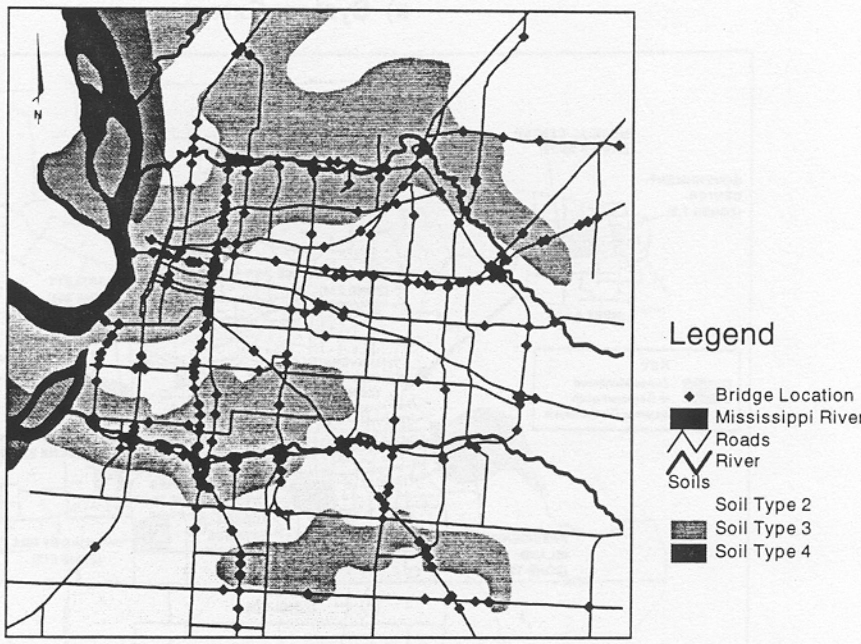


b) Origin - Destination Zones

FIGURE 2. MEMPHIS TENNESSEE HIGHWAY-ROADWAY SYSTEM

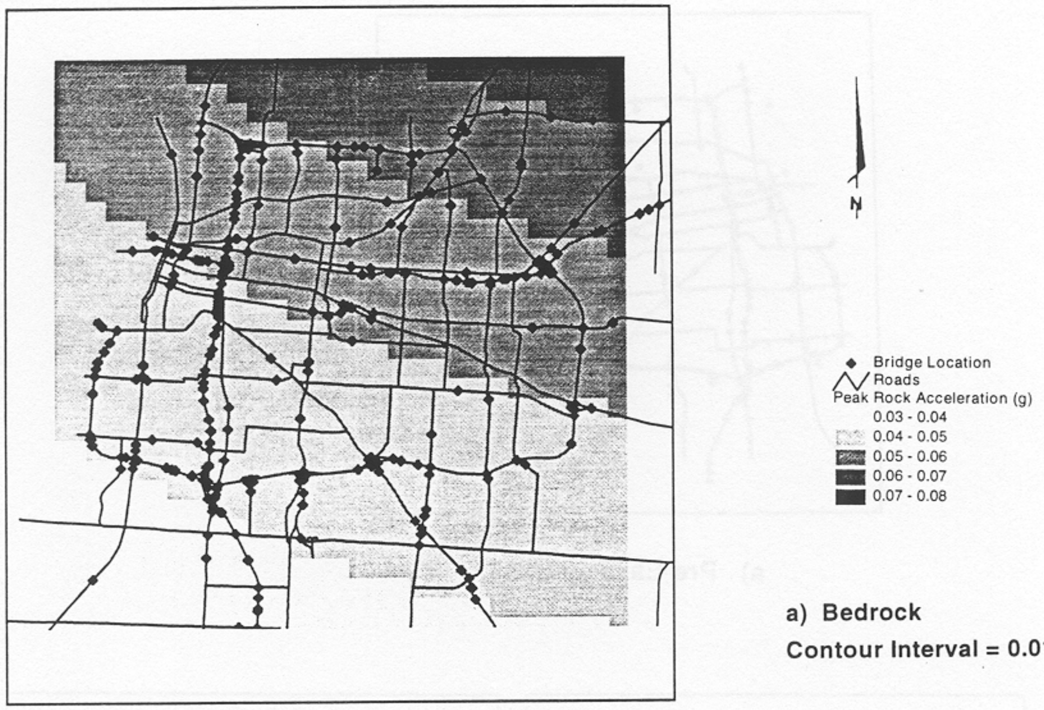


a) Scenario Earthquakes



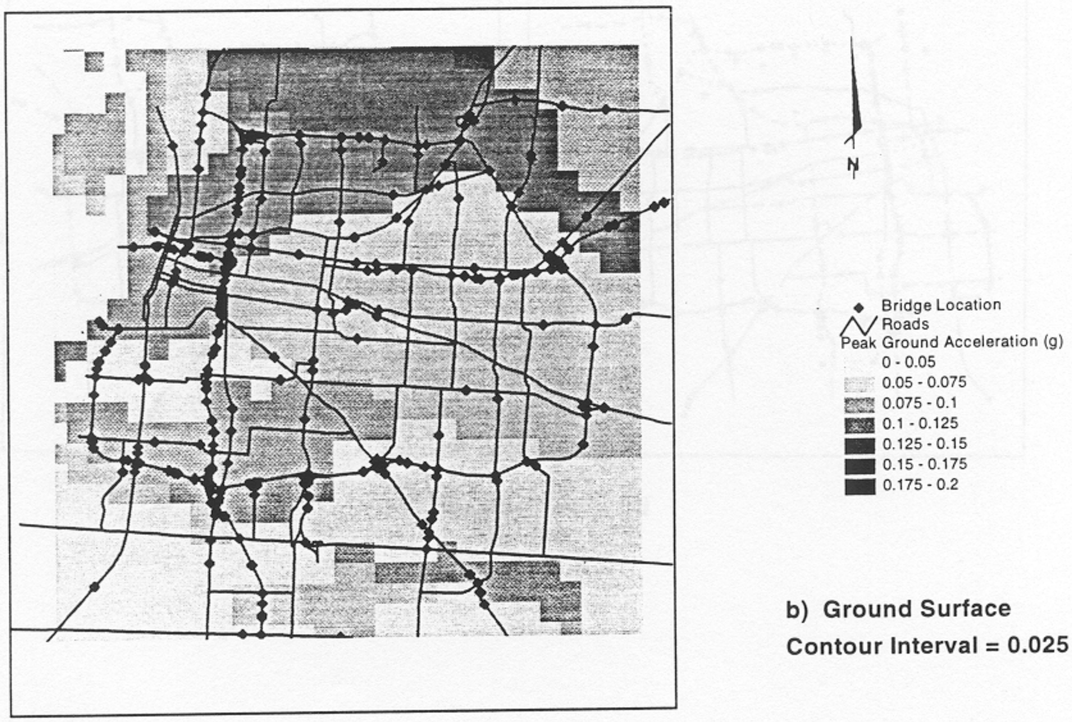
b) Local Geology (Hwang and Lin, 1993)

FIGURE 3. SCENARIO EARTHQUAKES AND LOCAL GEOLOGY



a) Bedrock

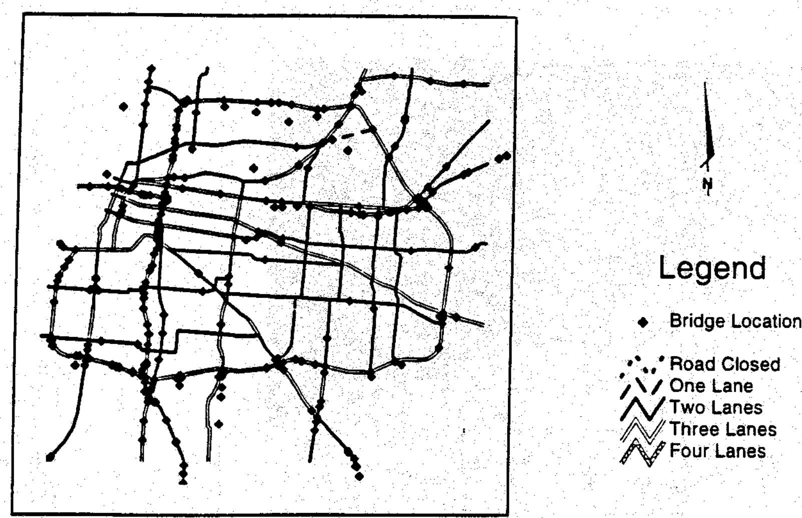
Contour Interval = 0.01 (g)



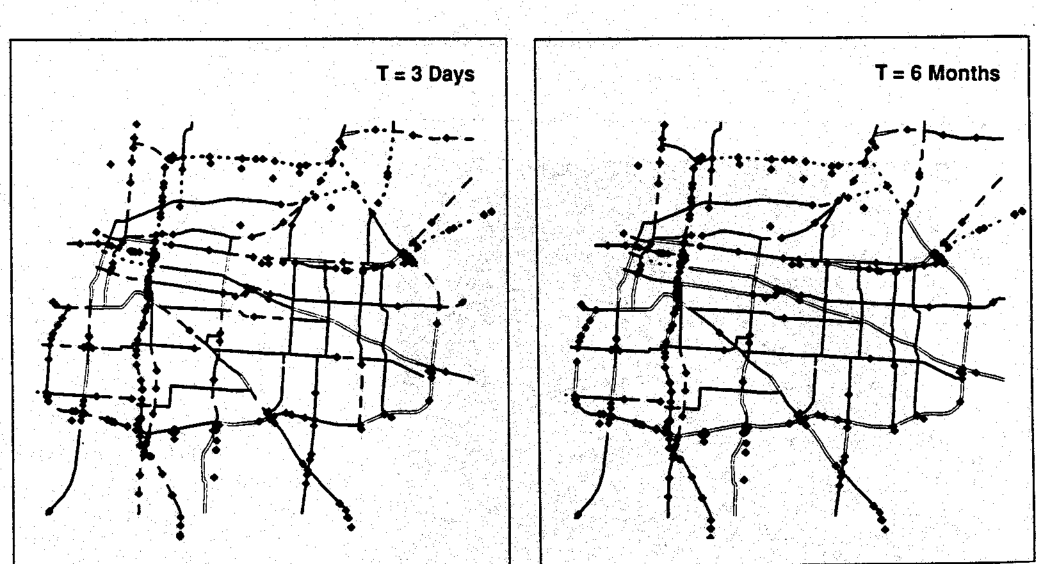
b) Ground Surface

Contour Interval = 0.025 (g)

FIGURE 4. PEAK ACCELERATION (G) DUE TO EARTHQUAKE "D"



a) Pre-Earthquake



b) Post-Earthquake

FIGURE 5. SYSTEM STATES